CORRELATIVE ANATOMY OF THE PELVIC FLOOR AND THE VISCERA WHICH TRAVERSE IT

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THIS THESIS IS DEDICATED TO

PETER,

ANN AND

RICHARD,

WHO HAVE HELPED ME GREATLY

INTRODUCTION.

GENERAL INDEX.

SECTION.

INTRODUCTION.

Feci quod potui: Faciant meliora potentes
(I did what I could, allow others to do better)
Inscriptions on graduation dissertations in old Russia.

This work began with a search for the pubo-recto-analis muscle at the instigation of Professor J.H. Louw.

Requests followed from surgeons and urologists for information about, and demonstration of, structure related to the pelvic floor in infants and adults. These encouraged me to go more and more deeply into the anatomy of this region in Man. I found that welding of viscera to their fascial, muscular and bony environs is not described in current textbooks. The absence of clear-cut boundaries between some of the muscles, in areas where they are contiguos, is likewise never emphasised. The beautiful drawings in atlases and textbooks have a comforting way of reassuring us that all has been revealed about the pelvic floor and its viscera. However, when the time-consuming expedient of removing the superior fascia of the levator had already yielded dividends, in that failure to do this, had led generations of anatomists to misrepresent the commonest form of the origin of the pubo-coccygeus, it seemed worthwhile to pursue the fascia, muscles and terminal viscera and their nerves, in order to fully understand their complex interwoven relationships. The unusual electrical activity of the musculature was especially intriguing and demanded an explanation

My findings, many of which fully corroborate the findings of others, led me to a consideration of the factors which combine to produce the remarkably efficient functioning of intestinal and genito-urinary outlet mechanisms. It then appeared essential to adopt a correlative approach. Accordingly I have aimed to present a selective account of the soft tissues of the pelvis and perineum which is comprehensive and I hope useful. From it certain aspects, which appear of primary importance, should emerge clearly.

No meaningful study of the human pelvic floor can be undertaken without some reference to its comparative anatomy. First hand comparative investigation has been limited in this study to random samples of a few key forms, its main purpose being to furnish a check on existing comparative descriptions, and occasional,far-fetched generalisations in the literature and to challenge and augment old interpretations rather than to suggest alternatives.

PLAN OF STUDY.

Enucleation specimens as well as gross,and a limited number of histological sections,in parasagittal,sagittal and coronal planes have been used to build up a composite picture of the following:

I. The pelvic fascia. - study of this has led me to develop what I believe is a new approach to this tissue and its functions.

II. The morphology and functions of the pelvic floor musculature with especial emphasis on the levatores ani and their complex relationships. This includes original information about the pubo-recto-analis.

III. The layers which converge on the pelvic floor which are analysed in a series of diagrams.

IV. The viscera related to the above. Relevant features appeared to be:

1.Angles and/or Flexures exhibited by the three tubes, which traverse the pelvic floor. Remarks are made on their form, maintenance and obliteration.
2.Anchoring and Supporting mechanisms.
3.Venous Plexuses.
4.Gross Innervation of Pelvic Viscera.
5.Ganglia and Nerve endings.

6. Ano-rectum - Correlative Anatomy.
7. Urethra and Bladder - Correlative Anatomy.
8. Factors relating to Parturition.

In this section greatest accent has been placed on the ano-rectum which I have studied in some depth. In relation to the bladder and urethra and uterus and vagina, some important principles and analogies have emerged, but I am aware that their study and that of the relevant literature has been incomplete..

Throughout the relevance of this research to current clinical practice is outlined. Where indicated pertinent findings in embryology are used to amplify or elucidate contentions. Many features, accurately recorded in previous descriptions, have been confirmed, some, which are fully covered by standard texts or the literature, have received cursory attention. Others, on which there have been differences of interpretation or emphasis, have been largely clarified.

Most of the work has been done with dissecting microscopes cadavers but I have also tested my assumptions on unpreserved material and compared them with findings consistently recorded by surgeons, urologists and gynaecologists during the performance of pelvic operations. Agreement with the latter has been substantial. Histological study has been limited to a few specimens because we have only had facilities for it during the past two years and at first had many failures with both adult and prenatal material. The results obtained with histology have however:

(a) Corroborated the findings of others in many instances.
(b) Confirmed a suspicion raised by a suggestion that perhaps a plexus in the pelvic floor musculature might account for its bizarre vigilance. This suspicion was strengthened by my comparative and human dissections. It is that the key to the mysterious activity of the pelvic floor muscles lies in their innervation. A corollary to this has

been an attempt to explain the unique features of these muscles and to indicate directions for further research into them.

SECTION V.

1. Descent of Viscera
2. Continence
3. Nervous Control.

In this section are contentions about prolapse and incontinence which are broadly based. I have also undertaken the task of outlining the nervous control of the pelvic viscera and floor in the light of what is available in the literature. Reflexes are first considered and then a brief review of the central connections, especially those related to defaecation and micturition, is presented. This aims to bring order to a chaotic field but it is, at present, entirely based on the findings of others.

The material used is indicated in Tables I through to V and illustrations, to which cross references are made in the text, are to be found in the accompanying albums. Most of the illustrations correspond sequentially with the text but to avoid bulk this has not always been possible.

The thesis ends with a summary of the findings, conclusions based on them and with questions which still require an answer.

ACKNOWLEDGEMENTS

I should like to record my grateful acknowledgement of the help given me by Professor L.H. Wells in whose Department this study has been perpetrated, and by Professor J.H. Louw whose unfailing interest and enthusiasm have encouraged me to continue it.

I am deeply indebted to Dr. Richard Hewlett for all the hours he has spent staining nerves, helping with the interpretation of histological sections and taking photomicrographs. Grateful appreciation is offered to Miss Ann Levett who most cheerfully has devoted much of her time to making and staining sections, taking photographs and arranging the illustrations in the albums.

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To Mrs. O. Enslin goes a particular tribute for the wholehearted way in which she used her great talents to transmogrify some of my drawings into pleasing colour plates. Thanks are also due to Mr. R.P. Wheeler who most kindly photographed these plates and arranged for their reproduction.

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/Overseas ....

Overseas colleagues have been highly co-operative and I wish especially to thank Professor G.J. Romanes of Edinburgh, Professor Scothorne of Newcastle, Professor Sinclair of Aberdeen and Professor Boyd of Cambridge for the opportunity to study material in their Departments of Anatomy. Dr. D.G. Morton of Berkely, California kindly allowed me to use bony outlines, which he had prepared from his own specimens, in Figs. 2.37 and 2.38, and I herewith thank him again.

Professor P.V. Tobias kindly allowed me to dissect his chimpanzee and Professor R. Trevor Jones made baboon material available to me and was most helpful during the time I spent in his laboratory in Johannesburg. I herewith thank them both.

Finally I thank the many colleagues who have provided me with material to work on and those enquiring students, from whom through the years I have learnt so much.

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SECTION I

/5) ....

THE PELVIC FASCIA

PART I

1) Discussion

As so much has been written about the pelvic fascia I feel that I must first justify this attempt to reconsider fascial arrangements by quoting from some of the material to be found in the following current anatomical texts:

1. Gray's Anatomy, 34th edition
2. Cunningham's Textbook of Anatomy
3. Hollinshead 'Anatomy for Surgeons'
4. Hamilton, Boyd, le Gros Clark - Textbook of Human Anatomy
5. Lockhart, Hamilton and Fyfe - Anatomy of the Human Body
6. Tobias and Arnold - Man's Anatomy
7. Ellis's Anatomy
8. Lee MacGregor - Synopsis of Surgical Anatomy
9. A Companion to Medical Studies - ed. R. Passmore - (the most recent and revolutionary textbook).

The name fascia implies a sheet or enclosing membrane as contrasted with areolar tissue which consists of loose packing tissue. It is possible as in the pelvis to have areolar tissue commingled with membranous fascial sheets as I shall presently describe. Most are agreed that there exist:

A. Fascial sheaths for the pelvic muscles - the parietal pelvic fascia

B. Fascial sheaths of the pelvic viscera - the visceral pelvic fascia.

Some mention extraperitoneal tissue forming sheaths or ligaments for viscera and a few indicate attachments of visceral and parietal layers and sheaths related to blood vessels. Lee MacGregor gives an ingenious description but he fails to gather the fascial entities into a convincing whole and the extraperitoneal tissues certainly do not receive the consideration they deserve.

/The ....

The Companion begins in a promising way:
"The bony and muscular walls of the pelvic cavity are lined by a layer of fascia which is continuous through periosteum with the fascial envelope of the abdominal cavity. This fascia is separated from pelvic peritoneum by extraperitoneal tissue. In the upper part of the pelvic cavity this layer is comparatively thin but below it forms an extensive zone in which the extraperitoneal parts of many pelvic viscera are embedded. Although different zones of this tissue vary in density and may be given distinct names it is to be appreciated that they are only subdivisions of the continuous pelvic fascia" - so far so good - he then goes on to describe in the section on reproduction the parametrium within the broad ligament as a separate entity with its various sub-divisions - he then states that "this parametrium provides the main support to the uterus and upper vagina preventing its downward prolapse. In this it may be aided by the tone of the levatores ani and the pelvic fascia."

Gray states that various parts of the pelvic fascia are considered as fascial supports of the rectum which must be divided to mobilise it and describes a stout avascular cord passing from the anterior surface of the lower part of the sacrum to the posterior aspect of ano-rectal junction, which is termed the 'fascia of Waldeyer' and a lateral ligament of the rectum surrounding the middle rectal vessels is also described.

Hollinshead calls the sacro-genital cord, which is covered by the sacrogenital fold of peritoneum, the lateral true ligament of the bladder whereas Gray, who gives no reason for the raising of a sacrogenital fold, calls it the posterior ligament of the bladder.

Hollinshead states that the attachment of perivascular tissue along the lateral pelvic wall to the fascia covering the levator ani has been referred to as the 'white line of the pelvic fascia' - it has been variously described as:

(a) coincident with arcus tendineus of levator ani,

(b) following a variable course but usually lying below that of levator ani,

/(c) ....

(c) being marked only over the upper or posterior surface of pubo-coccygeus,

(d) as not being present at all.

He then goes on to make this extraordinary statement

"The term apparently referred to the appearance of this area of attachment from the outside of the pelvic musculature after removal of the bony pelvis" ! This could only refer to the strong line of adherence to the outer aspect of levator ani caused by the sheath round the internal pudendal vessels and associated nerves (pudendal canal.). The obstetrical text-books I have consulted have followed the non-lead given by the anatomists.

The literature abounds with descriptions of the pelvic fascia, all of which have had their impact at the time of writing. Pre-eminent among these are the scholarly writings of Elliot Smith (1908). Authors range from Ricci et al (1947) who seek to prove that the pelvic fascia is virtually nonexistent to Curtis et al (1940), who have performed detailed studies and described many subdivisions which do not hold up under close examination - enormous and excellent in many respects although their contribution has been their 'collars', which they describe as 'endopelvic' fascia and which are formed by the lateral ligament of the bladder just cannot be made to fit; their 'pillars' of the bladder are very variable and are a part of the utero-vaginal fascia - only in a very tenuous way can they be followed into continuity with the pubo-vesical/urethral ligaments, i.e. by tracing strands along the bloodvessels of the bladder neck. I can find no justification for the term pubo-cervical ligament but the effect such a term can have is illustrated on p. 341 Fig. 161 in Tobias and Arnold (1967) where a massive sling from the cervix is seen embracing the bladder nowhere near its neck, and passing onto the pubic bone. The relationship between the bladder neck, urethra and the pubis is most remarkable in this diagram.

I shall now outline a scheme of the pelvic fascia for your consideration and will comment briefly on comparative aspects which seem of relevance. I shall in Section 5 consider some applications of this knowledge which surgeons have, sometimes unwittingly,

/used ....

used to great advantage. The points made are illustrated by diagrams and photographs and the section concludes with a note on the functions of the pelvic fascia.

The pelvis is of course separated from the perineum from fore to aft by:

(a) the urogenital diaphragm)
(b) the levatores ani muscles)
(c) coccygeus muscles) and their fasciae

and from the gluteal region by the piriformis.

The pelvic fascia is far less prominent in infants and children and in adults it varies very considerably in amount, both in health and disease.

2) <u>Components of the Pelvic Fascia</u>

Having removed the peritoneum it is evident that the pelvic fascia can be described under three headings:-

(i) Parietal
(ii) Septal
(iii) Visceral

(i) <u>The parietal layer</u> forms the epimysial fascial sheathes clothing the muscles i.e. the levator ani, with its extension to the pelvic brim covering obturator internus, and over coccygeus and pyriformis of each side. These sheathes form a truly parietal layer and reinforce only two of the ligaments of the pelvis:-

pubo-prostatic
lateral 'true' ligament of the bladder.

(ii) <u>Septal layers</u> - these are formed by extra or subperitoneal connective tissues which contains smooth muscle and varies in amount from a gross bulky mass to a membranous web in which the contained

visceral vessels (blood and lymphatic)
autonomic nerves
ducts - vas and ureter

/and ....

and remaining ligaments of the pelvis may be delineated. The septal layers may be sub-divided as shown in Fig 1.1 and Plate 1.2 and Fig 1.3 into a peripherally sited part which is everywhere medial, or within, the parietal layer and consists of an anterior curved septum, interrupted by the bladder, called the umbilico-vesical fascia (U.B.F.) and a posterior 'hammock like' curved septum known as Waldeyer's layer of fascia which is fully described. These septa meet on the side wall of the pelvis - an arbitrary dividing line being the vas (ductus) deferens in the male and the round ligament of the uterus in the female running from the deep inguinal ring to their separate destinations within the pelvis. Fig 1.1 shows the relationship of Waldeyer's fascia to the rectum, round ligament and vas. Plate 1.2 shows the attachment to the sacrum behind. In this plate the rectum should not have fascial bands passing laterally. In Fig 1.3 Waldeyer's layer is about to join the ano-rectal junction. The umbilical arteries, patent and obliterated, pass from the posterior to the anterior septum. Transversely directed septa are three-fold:-

a) Recto-vesical septum of Denonvillier's or rectovaginal septum
b) A condensation of the utero-vaginal fascia passing between the bladder and vagina. Its analogue in the male is the false capsule of the prostate
c) Supragenital septum in the male.

These blend with the peripherally sited septa.

iii) Visceral Layers - these are composed of the intrinsic fascia investing any organ e.g. the tela subserosa of the bowel + contributions from parietal and septal layers.

Visceral fascia invests to a varying extent different parts of the pelvic organs.

I shall describe each of these components in turn:

/ PART ....

PART 2

PARIETAL SUPERIOR FASCIA OF LEVATOR ANI

1) Lateral Ligament

The superior fascia of the levator clothes the upper surface of the muscle and is continuous round the medial free edge of the muscle with the inferior fascia which lies on the lower aspect of the muscle. It is of especial importance because:

Having ensheathed the pubo-prostatic/vesical ligaments anteriorly part of it is reflected as a shelf - the 'leitenplatte' of Pernkopf (1964) or LATERAL ligament of the bladder, which passing medially, usually below the tendinous arc of the levator ani, reaches the infero-lateral aspect of the bladder close to the bladder neck overlying the lowest members of the vesical plexus of veins. It appears to pass upwards blending with the visceral coat of the bladder which clothes antero-posteriorly coursing vessels and nerves and which here is largely formed by the continuation of the umbilico-vesical septal layer.
In both sexes behind the lateral margin of the bladder it is reflected onto the peripheral septal layers. The shelf extends back to the ischial spine where a cul-de-sac is found which is the posterior end of the retro-pubic space. In relation to the shelf and the whole retro-pubic space a varying amount of fatty and loose areolar connective tissue is found.

It is distinctly less prominent in the infant than adult.

In the female the posterior part of the lateral ligament behind the bladder blends first with the umbilico-vesical fascia and then with Waldeyer's layer behind the round ligament of the uterus and it is to this part of Waldeyer's layer that the recto-vaginal septum becomes attached.

In the male behind the bladder it also blends first with the umbilico-vesical fascia and then is reflected onto the part of Waldeyer's layer carrying the nerves and vessels of the sacro-genital cord and this cord thus intervenes between the retro-pubic and

/retro....

retro-vesical space of Uhlenhuth (1953). With this part of Waldeyer's fascia the posterior layer of the recto-vesical septum becomes continuous and so gains a vicarious attachment to the white line of the pelvic fascia which will now be defined.

2. White line of Pelvic Fascia

The peripheral septal layers with their contents always lie MEDIAL to the parietal superior fascia of the levator and where these layers merge with each other i.e. in relation to the lateral ligament of the bladder and posterior to it, a thickened irregular line marking their site of fusion is sometimes seen and is known as the 'white line of the pelvic fascia.' Photo 1.4 shows the pubic symphysis anteriorly, the bladder pulled medially, and the superior fascia of the levator covering the muscle and, in the shadow, passing onto the bladder wall. Photo 1.5 shows the anterior end of the left lateral ligament and the reflection of superior fascia over the pubo prostatic ligament. Plate 1.6 shows the parietal and septal layers joining in a coronal section. This line lies in relationship to the lateral pelvic wall and it parallels the arcus tendineus of the levator ani lying usually below as shown in Photo 1.7, but sometimes coincident with this commonly encountered structure. Photo 1.7 shows fenestration of the superior fascia of the levator and an abnormal obturator artery and vein on the left. In relation to the bladder it is formed by a fusion of the visceral coat, which in this region is a continuation of the umbilico-vesical septal layer, which has split to enclose the bladder. It is foreshadowed in some lower primates but does not develop fully in any species except Man, although even here its presence is variable.

3. Arcus Tendineous of Levator Ani

This well marked feature when present, as it is in about 66% of cases, appears to be an intrinsic part of the superior fascia of the levator. It is clearly shown in Photo 1.8. The arch is frequently explained as a slipping down of origin of the levator ani from the pelvic brim to the side wall of the pelvis but this is not satisfactory as some muscle fibres arise above it, and then join it, and also some muscle fibres arise from it, and pass downwards and one can with care, always dissect tendinous fibres proceeding from it up to the brim of the pelvis. It is not often fully coincident with muscle fibres of pubo- and ilio-coccygeus as illustrated in most current text books. Its position varies, but posteriorly it begins at or within 2.5 cm of the tip of the ischial spine on the medial aspect of the lateral pelvic wall and extends anteriorly to the back of the body of the pubis between its upper border and its lower border. Its anterior attachment is always above the attachment of the pubo-prostatic/vesical ligament as illustrated in Fig 1.9 and Photo 1.10. It lies, as mentioned earlier, either above or coincident with, the 'white line of the pelvic fascia' and it is noteworthy that Lockhart et al (1959), having stated that the levator arises from the tendinous arc of the levator illustrate the levator with a 'low' origin, see Section 2, arising from the 'tendinous arch of the pelvic fascia' which one hopes in this case was coincident with it. Varying numbers of fibres of pubo- and ilio-coccygeus arise from the arc as will be considered when these muscles are described.

In some the densely packed parallel collagen fibres give the impression that a pull has been exerted away from the back of the pubic bone. It is tempting to believe that when the pelvis is more vertically disposed the arcus develops strongly having more strain imposed on it by the pelvic fascia, septal and parietal, which has fused along the white line of the pelvic fascia.

The arci in any case seem as Peter Thompson (1901) originally suggested to have developed as an adaptation to the upright position. The pubic ligaments will be described in relation to the visceral coat of the bladder.

4. In the Male

Immediately below the lateral ligament, as well as medial to the pubo-prostatic ligament, the superior fascia forms the anterior

/and ....

and infero-lateral aspects of the false capsule of the prostate being separated from the gland by the prostatic plexus of veins. This lies immediately behind the pubis and arcuate sub-pubic ligament and is connected with the deep dorsal vein and other veins from the bulb of the penis as well as with pudendal and obturator channels. It is shown in Plate 4.7.

This fascia with underlying muscle fibres (levator glandulae prostatae) forms a sling round the prostate which is inserted into the perineal body and serves to maintain the all important posterior urethro-vesical angle.

Below the prostate the fascia blends with the fascia of the urethral wall as it begins its membranous part and round this fuses with the fascia of the upper layer of the urogenital diaphragm (Deep perineal pouch). This fascia is composite of obturator fascia, which reaches it via the posterior wall of the pudendal canal, the inferior fascia of the levator and the superior fascia already mentioned.

5. In the Female

The superior fascia passing round the medial free margin of the levator to become its inferior fascia sends a prolongation into the sulcus between the pubo-vesical/urethral ligaments which obscures the dorsal vein of clitoris and then firmly adheres to the wall of the urethra immediately below the bladder before contributing to the superior fascia of the urogenital diaphragm which is constituted of the same elements as it is in the male.

Passing down below the lateral ligament behind the pubo-vesical ligament the superior fascia blends with the lateral vaginal walls and here incontrovertible evidence is found of underlying levator fibres becoming attached to the vaginal walls as well as passing behind the vagina into the perineal body.

6. In relation to the walls of the ano-rectum in both sexes, the superior fascia and underlying muscle fibres add an important

/fascial ....

fascial and muscular contribution to the conjoined longitudinal coat. In some cases the contribution takes the form of fibro-tendinous shining 'claws' and it is not possible to say whether these connective tissue (tendon cells) take origin from the superior fascia or from the levator muscle. Such cells are immensely strong and can only be torn apart and not broken (Cronkite (1935)). This matter will be given further consideration when the factors concerned with continence and the strength of the pelvic floor are reviewed.

7. It is thus seen that the perineal body receives a significant endowment of fibrous tissue and muscle and the visceral coats of the prostate, urethra, vagina and rectum receive fascial reinforcements from the superior fascia of the levator.

8. Those parts of the fascia not related to the pelvic organs and perineal body in the manner described, clothe the upper surface of the levator ani muscle and posteriorly, above the stratified ano-coccygeal raphe, fascia and muscle reinforce the ligament and muscle of Treitz (recto-coccygeus), which lies in this position at the ano-rectal junction and is obscured by this fascia, as shown in Photo 1.11, which also shows the perineal body between the rectum and urethra anteriorly.

PART 3
SEPTAL

1) The sub- or extra-peritoneal connective tissue comprising the septal layers as stated earlier, may be resolved into a peripheral layer, interrupted anteriorly by the bladder, which receives transversely directed septa which differ in the two sexes.

The umbilical arteries patent and obliterated pass from Waldeyer's posterior 'hammock' layer forwards into the anterior umbilico-vesical layer of fascia. They are the uppermost clearly defined vessels in the septal layers.

/ Posterior ....

Posterior and Anterior Curved Septa

Photo 1.12 shows a male hemipelvis divided to the right of the midline. Peritoneum which has been mainly detached has been draped into an approximation of its usual position. Photo 1.13 shows the peritoneum retracted caudally but still attached to the antero-lateral rectal wall. It will be seen that a continuous sheet of fascia stretching from the lateral edge of the bladder to behind the rectum is still present. In it the vas and ureter can be discerned and some autonomic nerves can be seen passing towards it posteriorly. This sheet is U.B.F. in front of the vas, and Waldeyer's fascia behind it. Waldeyer's layer has been detached from the sacrum behind. Parts of Waldeyer's layer and the anterior-septum or U.B.F. are shown in Photo 1.14 which is of a coronal section. The peritoneum has been elevated and in the fascia the right vas can just be discerned. In Photo 1.15 Waldeyer's layer can be seen joining the rectal wall.

2. The Posterior Curved Septum - Waldeyer's Layer/Fascia (Presacral Fascia).

According to Last (1959), Waldeyer first described this presacral layer in 1899; Close (1947) however attributes the first description of this layer to Merkel in 1907. The currency of the name 'Waldeyer's layer' appears to derive from Gabriel (1948), who described it as the 'suspensory ligament of the rectum.'

This peripherally sited extra-peritoneal layer forms a curved septum stretching across the posterior pelvic wall behind the rectum which Roberts et al (1964) have aptly described as a 'hammock'. Above it blends with the extraperitoneal tissue of the posterior abdominal wall. Below it converges on the pelvic viscera. Thus it sweeps in to join the posterior wall of the ano-rectum, the cervix and vagina of the uterus in the female and the prostate, seminal vesicles and vasa in the male. It is firmly attached to the ano-rectum where it blends with:-

(a) the tela subserosa (intrinsic visceral coat)

(b) the fibrous ligament of Treitz

/(c) ....

(c) the superior fascia of the levator

thus completing the fibrous component of the conjoined longitudinal coat of the ano-rectum.

Posteriorly it is bound to the sacrum and posterior and postero-lateral pelvic wall by bands in relation especially to the nervi erigentes and sympathetic fibres passing to the pelvic plexuses and in relation to the vessels proceeding from the neurovascular pedicle to the pelvic viscera - it is thus firmly tethered to the sacrum behind.

Postero-laterally this sheet in its passage from the midline to its union with the umbilico-vesical fascia is anteriorly and antero-medially continuous with the connective tissue and smooth muscle of the broad ligament and supra and recto-vaginal septa in the female and with the sacro-genital cord, supragenital and recto-vesical septa in the male before joining the anterior septal layer.

This key septum invests and carries the hypogastric plexus of autonomic nerves, the pelvic (inferior hypogastric) plexuses deriving from the superior hypogastric with their accessions from (2) sacral sympathetic chain and (1) nervi erigentes. These points are illustrated in Figs 1.16 and 1.17. I cannot agree with Smith and Ballantine (1968), who state that the vesical nerves 'run along the lateral wall of the pelvis outside the pelvic fascia' and that they are protected from injury during excision of the rectum and after abdominal and vaginal hysterectomy by their position 'outside the pelvic (Waldeyer's) fascia.' [1] On the other hand their remark that the 'correct plane

/medial ....

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1. Footnote Roberts et al (1970) describe Paitre, Giraud and Dupret (1935), Goligher (1967) and Ballantine and Smith (1968) (see above) as stating that the pelvic splanchnic nerves lie outside the posterior fibrous sheath of the rectum and hence outside the presacral fascia; especially the nerves passing to the bladder lie outside the 'parietal pelvic fascia of Waldeyer at least until they reach the vesico-vaginal region.' However, Ashley and Anson (1946), Uhlenhuth (1957), Wolfe, Smith and Middleton (1948) and Wilson (1967) have findings in accord with their own in that they conclude that the pelvic splanchnic (nervi erigentes) including those supplying the bladder are embedded in the presacral fascia for a considerable part of their course.

(medial to the pelvic fascia) is easily found from above' but difficult to locate when using a perineal approach is correct. Therefore in a combined abdomino-perineal operation the abdominal operator must define Waldeyer's layer and thus avoid damage to nerves. Clearly the important step is to keep medial to the fascia which CONTAINS the nerves and thus avoid injuring them whenever possible.

In addition because of its extension into the broad ligament in the female Waldeyer's layer -

(a) forms most of the ligaments (true) of the pelvic as will be explained later, and

(b) blends with the wall of the rectum and uterus so adding to their visceral coats.

In the male, as already noted, it provides the connective tissue element of the sacro-genital cord, which emerges with the fascial covering of the seminal vesicles, terminal vasa and supragenital septum. It contains the ureter and ductus deferens in the male as illustrated.

The proximal parts of all the visceral branches of the internal iliac vessels with accompanying lymphatics travel in Waldeyer's layer of fascia. Some of these are shown in Plate 1.6 as are relations of ureter to uterine artery. Complex venous, vascular and nervous elements are apparent in this layer. Photo 1.18 shows the posterior half of a coronally cut pelvis and shows how a tortuous uterine artery can have a prolonged relationship to the ureter, the cut edge of which can just be discerned near the bottom of the picture. Photo 1.19 is also of a coronal section. Note cut bladder with ureteric orifices visible. Behind the bladder and to the right of the uterus nerves and vessels converging on these organs can be seen and the uterine artery has its classic relationship to the ureter. Photo 1.20 shows the relationship of the ureter to the very large ovary of the new born female infant.

Postero-laterally Waldeyer's fascia blends with the neuro-vascular pedicle which covers the greater sciatic notch and piriformis

/posteriorly ....

posteriorly and occupies the interval between the utero-sacral ligament medially and the 'white line of the pelvic fascia' whose posterior extremity it forms laterally. From this point forward it fuses with the parietal fascia as described so forming the posterior part of the 'white line of the pelvic fascia.'

3. <u>The Anterior Curved Septum (Umbilico Vesical Fascia) (U.B.F.)</u>

This septum is interrupted by the bladder, which it splits to enclose, thus giving a reinforcement to the visceral coat of this organ which extends onto the terminal ureters in relation to the peri-ureteric plexus of veins and loops of autonomic nerves. This layer extends to enclose the umbilical arteries (obliterated and patent) and the urachus and in the foetus can be seen to blend laterally and anteriorly with the transversalis fascia and fascia iliaca - this relationship is obscured when the bladder becomes a pelvic organ. The upper part of the superior surface is very lightly clothed with fascia and here smooth muscle from the bladder wall is liberally inserted through the fascia into the peritoneum. The layer which passes over the infero-lateral surface of the bladder is considerably thicker and invests the numerous veins which are travelling backwards from the prostatic and vesical plexuses. It is joined by the lateral ligament formed by the parietal layer of superior fascia as described earlier, which forms the anterior part of the white line. This layer is described in slightly different terms by Hammond et al (1941) although my findings agree with theirs substantially. The layer is present at an early stage in embryonic life and is illustrated in <u>Photo 1.21</u> surrounding the umbilical arteries. <u>Photo 1.22</u> shows the fascia between the urachus and umbilical arteries in a new-born female infant. Herniation of a nubbin of umbilico-vesical fascia through the obturator foramen is shown in <u>Photo 1.23</u>. This would have appealed to Moschowitz (1912).

The pre-umbilico-vesical fascia, which is mentioned for completeness, was first described by Cuneo and Veau in 1899 (quoted by Roberts et al (1964)) as being formed by a fusion of peritoneal layers which wrap round the sides of the umbilical arteries

/in ....

in the foetus thus suspending these vessels and the urachus in a mesentery which is attached to the anterior abdominal wall.

This formation accounts for the occasional peritoneal pockets, found in relation to the obliterated umbilical arteries which are seen in the dissecting room and occasionally act as hernial sacs.

4. Transversely orientated Septa

(a) Definitions

These firmly connect the peripheral curved layers on each side of the pelvis and are:-

1. The well known septum of Denonvillier and its counterpart the recto-vaginal septum, which tends to adhere firmly to the posterior vaginal wall.
2. A transverse fascial condensation linking the vasa and capsules of the seminal vesicles contains much smooth muscle which often raises a crescentic peritoneal fold which is concave posteriorly and has been termed by Uhlenhuth (1953) the recto-vesical fold of peritoneum (see Photo 1.24). It is called the supragenital septum. Below the fold the finger can reach the depths of the recto-vesical pouch and feel the base of the bladder. In relation to the fold and just above it the seminal vesicles and vasa are palpable through the peritoneum. Laterally the supragenital septum joins the septal peripheral layers.
3. A condensation of variable proportions of the utero-vaginal fascia, containing much smooth muscle, passes between the cervix and vagina and the bladder in the female. Its analogue in the male is the false capsule of the prostate. It was first fully described by Richardson (1929). This includes the so called pillars of the bladder and the supravaginal septum which corresponds to the supragenital septum in the male.

/(b) ....

(b) Recto-vesical Septum (Denonvilliers Fascia)

Close (1947) states that Tyrell (1794 - 1843) first described this layer which received Denonvillier's name in 1837. Elliot-Smith (1908), Roberts (1964) and Uhlenhuth (1953) are amongst those who have given a good description of this entity. Superiorly the septum adheres to the lower limit of the peritoneal recto-vesical pouch. Inferiorly it merges with the anterior upper border of the perineal body and when it exhibits a double sheet it is the posterior of the two which has this attachment, the anterior leaf forming a posterior capsule for the prostate and blending with its apex below. Anteriorly it gives origin to the tough layers which enclose the seminal vesicles and vasa and in this region above it merges with the supra-genital septum. Posteriorly smooth muscle fibres from the bowel wall can be seen to join this layer in sagittal sections. Laterally the septum joins Waldeyer's layer of fascia close to the latter's point of attachment to the 'white line of the pelvic fascia.' In my experience this septum is nearly always but not invariably present. The disposition of the septum in the male is illustrated in Plate 4.7 and Photos 1.25, 1.26 and 1.27.

Photo 1.25 is of a coronal section which shows the anterior layer hooked between the seminal vesicles and vasa and the posterior layer lying just in front of the rectum. Between them is the space of Proust. Photo 1.26 shows a very fatty layer of Waldeyer and the classic peritoneal relationship of Denonvillier's septum. Photo 1.27 shows a peritoneal pocket at the bottom of the recto-vesical pouch,on the left side it is still attached to the septum and has been pulled aside so that the septum is shown. The rectal lumen shows antero-posterior compression and is just passing forward to the perineal flexure. Anterior to the septum vasae and seminal vesicles can just be seen.

Histology shows the septum to be a fibro-muscular elastic layer of dense collagen fibres, abundant smooth muscle and some elastic fibres. Thin-walled branches of the middle rectal vessels

/and ....

and autonomic nerves are also in evidence.

The controversy about whether this septum is derived from peritoneal fusion or condensed areolar tissue still continues. Arguments for peritoneal fusion of which Uhlenhuth (1953) and Milley and Nichols (1969) are staunch supporters are:-

1) Firm adherence to lower end of recto-vesical or recto-uterine pouch.
2) The appearance of adhesion in the depth of the recto-uterine/vesical pouch in occasioned specimens.
3) Appearance - it resembles peritoneum.
4) Division into anterior and posterior layers in some cases - but this does not account for the attachment of the anterior layer to the apex of the prostate.
5) In some specimens small cyst-like spaces have been located in relation to it.

Silver (1955) however puts forward some cogent arguments in favour of its being a mesenchymal condensation. In embryos and foetuses he found:

1) There is no histological evidence of fusion of peritoneum, as can be found posterior to the duodenum where islands of peritoneal cells can be seen, and thickening due to fusion known as zygosis, can be demonstrated.
2) Artefact resembling zygosis may be due to tangential sections or to block compression of the embryo.
3) Measurements of the relationship of the recto-vesical pouch to the genito-urinary system and rectum revealed that:
    a) the recto-uterine and recto-vesical pouches remained constantly related to the main valve of Houston from the time it frequently appears at about 4 months until birth.
    b) the bladder neck descends just before birth - this is shown by a change in the direction of

/the ....

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/the ....

the vertically running fibres of the pubo-prostatic/vesical ligaments which become horizontal at this time. This creates the impression that the pouch has risen to a higher level than in fact it has.

c) if the distance 'promontory to pouch' is expressed as a percentage of the distance 'promontory to perineum' it is found that during early stages the pouch lies close to the perineal surface, thereafter the distance increases and by the 4th month the ratio 'promontory to pouch'/'promontory to perineum' falls within the limits observed in the adult.

d) longitudinal smooth muscle from the rectum can be seen entering it from behind at the 4th month, although, as much smooth muscle joins the peritoneum from pelvic organs - this is not of much significance.

c) Recto-Vaginal Septum

Milley and Nichols (1969) firmly defend the slender recto-vaginal septum, which is homologous with the recto-vesical septum, in an impressive study totalling 143 specimens examined at surgery, autopsy, and in embalmed cadavers. These ranged in age from eight foetal weeks to 100 years and in every one it was present.

Its adherence to the posterior vaginal wall coupled with the difficulty in showing it histologically - Ricci (1947) - may explain why its existence has been denied. It is certainly not such a striking feature as the recto-vesical septum which is nearly always easy to demonstrate. A well-developed example is shown in Photo 1.28 which is a coronal section showing internal urinary meatus above, vagina behind the bladder, well defined septum joining Waldeyer's layer laterally and the rectum, with its anterior cut wall flapped towards us. Beneath the flap is the rectal lumen. There is no doubt of the very close

/relationship ....

relationship of the anterior rectal wall to the posterior vaginal wall and that the perineal body is definitely smaller in females than in males.

5. <u>Functions of Septal Layers</u>

a) Ensheathed by these septa are:

1) Pelvic visceral bloodvessels i.e. visceral branches of the internal iliac arteries and tributaries of the internal iliac veins

2) Lymphatic channels

3) Autonomic nerves

A) superior hypogastric plexus

B) inferior hypogastric or pelvic plexuses with their accessions from

i) nervi erigentes

ii) sacral sympathetic chain

4) Ducts - ductus deferens
ureter

5) Ligaments

All the smooth muscle, collagen and fibro-elastic tethering ligaments of the pelvis except parts of

the pubo-prostatic/vesical
lateral ligament of the bladder

are condensations of the septal layers. The ligaments excluded from the septal layers are formed by the vesical visceral layer, which is of mixed origin, swathed by the superior fascia of the levator as already described. They will be described with the visceral layers.

b) The septal <u>ligaments</u> in the female and male pelves will now be classified.

<u>In the female pelvis</u>

These ligaments are all related to the peritoneal BROAD ligament of the uterus and may be annotated as follows:

/1)....

1) In the upper part of the broad ligament is:-

A) the round ligament of the uterus, which, with the ligament of the ovary, is the homologue of the gubernaculum in the male. The round ligament is a triangular fan of smooth muscle, thickest where it underlies and is adherent to peritoneum of the anterior or inferior leaf of the broad ligament. It has its base along the lateral edge of the uterus as far down as the cervix and then passes out through the canal of Nuck becoming increasingly fibrous to blend either with the coverings of the inguinal canal where it is joined by striated fibres according to Imianitoff (1928) so that a cremasteric reflex in relation to the inguinal canal can be elicited, or to reach the labium majus; the ligament of the ovary binds this organ to the uterus.

B) the suspensory ligament of the ovary (infundibulo-pelvic ligament) carries the ovarian vessels and autonomic nerves from the posterior body wall

2) Radiating from the cervix and adjacent uterus and vagina abundant smooth muscle is to be found,

A) passing backwards from the postero-lateral aspect of the cervix and upper vagina and raising crescentic folds of peritoneum which skirt the rectum (recto-uterine folds of peritoneum) are the striking <u>utero-sacral ligaments</u> which are continuous with Waldeyer's layer posteriorly. They contain much smooth muscle and connective tissue as well as many autonomic fibres of the pelvic plexus. Fibres which interlace with each other at the back of the cervix at the level of the internal os uteri form the torus uterinus.

<u>Photo 1.29</u> shows peritoneum obscuring the bladder anteriorly and swathing the round ligament, uterine tube and utero-sacral ligament on the left. Behind

/the ....

the fundus of the uterus the rectal lumen is visible with peritoneum passing in front of the viscus and proceeding laterally. Waldeyer's 'hammock' can be seen passing behind the rectum carrying its vessels and nerves and behind the peritoneum which is best shown on the right, to curve forward and join the U.B.F.

B) continuous with the utero-sacral ligament, but lateral to it, is the condensation, which in its upper portion carried the uterine vessels and associated lymphatics and nerves, and below extends to the superior fascia of the levator on the pelvic floor. It extends from the uterus and vagina medially to become continuous with Waldeyer's layer laterally. This is known as the lateral, transverse or cardinal ligament of Mackenrodt.

C) the 'pillars' of the bladder have been considered in the introduction p. 3 , and form a part of the utero-vaginal fascia.

These ligaments are illustrated in diagrammatic form in Fig 3.2.

In the Male Pelvis

Smooth muscle and connective tissue elements, which invest the vessels and nerves of the bladder, terminal ureters, vasa prostate and seminal vesicles, form the sacro-genital cord or posterior ligament of the bladder, which are comparable to a combination of the utero-sacral and lateral ligaments of the uterus.

It will be remembered that the 'white line of the pelvic fascia' is a blending of septal and parietal layers designed to give support.

6. Comparative Aspects

The arcus tendineus of the levator ani is not found in animals except for the unusual position reported by Thompson (1901) in the

/Kangeroo ....

Kangeroo in whom three heads of origin of the levator are found - one from the pelvic brim, one from the region of the obturator foramen, and the third, which is superficial (caudal) to the other two, which passes in a tendinous arch from the ischial spine to the back of the pubis. As the Kangaroo is normally in an erect position this finding lends support to the hypothesis that the arcus develops as an adaptation to the forces imposed by the upright position.

In mammals up to primates the septal layers are poorly developed probably because as Hunter remarked, the contents of the pelvis do not adhere to the sides in the same way that they do in Man.

Blaisdell (1917) gives a fine account of the utero-sacral (sacro-uterine) ligaments and notes in a comparative series that there are smooth muscle bundles in certain pronograde mammals (guinea-pigs, Belgian hare, cat, dog) which are closely related to the recto-uterine folds of peritoneum. The increase in what he calls the parametrial, paravaginal and paraplical fibro-elastic tissue which constitute 'potential ligamentous aggregations' is remarked by this author in the monkey (Macacus). Fat deposits in an extraperitoneal position largely replace the peripheral septal layers in rats and dassies, and are also present in the retro-pubic space.

In dassies a well developed recto-uterine fold is present and firm strands of what appears to be smooth muscle reach the antero-lateral rectal wall and then pass backwards on each side of this viscus.

In rats no such condensation is observed.

In primates I have chosen the chimpanzee and the baboon to illustrate the pelvic fascia. Whereas in the baboon the parietal layers are exceptionally underdeveloped, in the chimpanzee a striking layer is present. Waldeyer's layer and the umbilico-vesical fascia is clearly marked in both species. These layers are shown in the baboon in Photo 1.30 and in the chimpanzee in Photo 1.31. In Photo 1.30 the pubic symphysis is in the right hand corner. The lumen of the rectum is identifiable. A hook holds the peritoneum forward so that the peripheral septal layer

/can ....

can be seen. Nerves entering this layer do not show in this picture, but they are present. In Photo 1.31 the pelvis is viewed from the left and the rectum is on the extreme left. Nervi erigentes and vessels can be seen entering Waldeyer's layer, which is well developed and curves round immediately outside the peritoneum. In the chimpanzee a recto-vesical dense layer of transversely arranged fascia is present. In one male baboon it is identifiable but in one female baboon it is very flimsy.

Occasionally in Man I have found Waldeyer's layer to form a double sheet, a condition Peter Thompson (1901) found in the orang-utang and in these cases the umbilical arteries patent and obliterated pass between the two layers. Both Peter Thompson (1901) and Elliot-Smith (1908) suggested that the connective tissue of the pelvis except for the fascial muscular sheathes is derived from the mesenchyme which gives rise to the bloodvessels - it seems equally possible that it is derived from the pelvic viscera and in any case its mesenchymal origin is not in debate.

7. Visceral Layers

The visceral coats of the pelvic organs are formed by an intrinsic investing layer reinforced by contributions from the parietal and septal layers. The importance of these contributions in taking the weight of these organs and conveying vessels and nerves to and from them can scarcely be overestimated.

a) Bladder

The layer surrounding the bladder consists of the intrinsic coat + the umbilico-vesical layer which has split to enclose it and this is thicker on the infero-lateral surface than on the superior one except where it projects round the terminal ureters. Finally the reflected parietal layer fuses as described in the lateral ligament with the continuing septal layer and thus forms the anterior part of the white line of the pelvic fascia.

b) Pubic ligaments

It is convenient at this point to complete the description of these important entities. In both sexes at the medial end of

/the ....

the white line stout fascial bands in company with smooth muscle pass from the bladder neck region to the pelvic wall. They have a curved form with the concavity of the curve facing medially as shown in Photos 1.5, 1.32 and Plate 4.7.

In the Male

Smooth muscle fibres pass from the bladder neck and prostate to the back of the pubis as shown in Photo 1.32, Plate 4.7 and Photos 1.5, 1.10 and 1.32.

Photo 1.32 shows the pubic symphysis and arcuate sub-pubic ligament on the right hand side. Medial to these are veins of the prostatic plexus joined by the deep dorsal vein. Above the plexus is the left pubo-prostatic ligament covered by superior fascia of the levator. It is slightly out of focus. The ligament passes from the bladder neck and prostate to the bone. The plastic tube passes from internal urinary meatus to the bulbar urethra. Prostatic and membranous regions can be distinguished and Cowpers gland is apparent just above the bulb.

The pubic fibres are joined by collagen bundles from the visceral coat of the bladder, i.e. intrinsic and anterior extension of umbilico-vesical fascia (septal) at the anterior end of the white line and are swathed, as described earlier, by the superior fascia of the levator.

In the Female

Smooth muscle bundles and fibrous bands extend from the bladder neck and upper urethra to the back of the pubis and to the arcuate subpubic ligament in some cases.

F Fig. 1.9 illustrates this point. In the foetus and neonate the bands from the urethra are very dense and well defined as noted by Krantz (1951) and hold the urethra well forward in relation to the pubis. Histology of the left ligament in a transversely sectioned female neonate is shown in Photos 1.33 a) and 1.33 b).

Photo 1.33 a) shows the smooth muscle in the pubo-prostatic ligament of the left side in the centre of the field. To the right is urethra. To the left is levator ani. Photo 1.33 b) is a high power view of the scene. Note nerves and vessels

c) Prostate and Seminal Vesicles and Vasa

The fascial prostatic capsule in which is embedded the plexus of veins is mainly formed by the superior fascia of the levator glandulae prostatae part of the pubo-coccygeus. Posteriorly the anterior layer of Denonvilliers' fascia completes the capsule.

The upper part of the seminal vesicles and the ampullae of the vasa lie in the supragenital septum of fascia as described and below, the seminal vesicles receive additional support from the anterior layer of Denonvillier's fascia.

d) Uterus and Vagina

The utero-vaginal fascia is much denser in relation to the vagina and cervix and is practically absent over the body and fundus of the uterus where smooth muscle binds these regions to the overlying peritoneum.

e) Ano-Rectum

We have considered in part the visceral coats of the ano-rectum and the formation of the fibrous elements in the conjoined longitudinal coat. The fate of this layer will be traced in a later section.

8) Functions of the Pelvic Fascia

The pelvic fascia is made up of three interdependent entities whose functions include:

i) Bearing the weight of pelvic and some abdominal viscera.

This is a key function which I have not seen described before with the explanations outlined below.

It includes:

resisting rises in intra-abdominal pressure;
standing in for pelvic musculature;
welding and strengthening;
supporting by the formation of thickenings termed ligaments.

This theory will now be elaborated on.

Because septal and parietal layers fuse with each other along the white line of the pelvic fascia on the side wall of the pelvis as described in some detail on p. 7 and because each are attached to, and contribute to, the visceral coats of the pelvic organs, much of the weight of the pelvic viscera is born antero-laterally by the thick parietal layer which extends over and above the levator ani muscles up to the pelvic brim. Posterior to the ischial spine the posterior septum of Waldeyer, which also converges on the pelvic organs and is reinforced by smooth muscle and connective tissue ligaments which, as they become anchored to the sacrum as described and illustrated, suspend the organs posteriorly and laterally. Because the parietal layer is continuous round the medial free margin of the levatores with the inferior fascia of the levator and because this in turn is continuous with the anal fascia covering the external anal sphincter the anal canal and its coverings is most firmly supported and suspended by a powerful fascial sheet.

This funnel of fascia is reinforced above by fascial strands of some strength passing to it from the obturator fascia in the upper recess of the ischio-rectal fossa. These are described in Section II Part 4.

Gratz (1931) working on the tensile strength and elasticity of the fascia lata found the former to approximate to that of soft steel

/weight ....

weight for weight i.e. fascia lata having SG 1.31 has an average ultimate tensile strength of approximately 7,000 lbs. per sq. inch (soft steel has SG 7.83 and an ultimate tensile strength of 45,000 lbs. per sq. inch). This strength is proportional to its area in cross section. Considering the dramatic declarations made by Joseph in 1963 pertaining to the maintenance of upright posture, certain conclusions seem justifiable. Joseph found that, when standing, the only muscles (excluding the pelvic) to show electromyographic activity are some lower thoracic para-vertebral ones and that therefore the upright posture can be maintained by passive factors such as joint capsules, ligaments and fascia and that stretching of muscles under these circumstances does not produce contraction.

He remarks that the 'mechanisms for maintaining the upright posture in Man are examples of adaptations of structure to function so that it is performed with the greatest economy of effort.'

Ligaments and other passive factors, e.g. fascia, are capable of performing the functions which they have now been given since they are powerful enough to withstand very large tensions and it is rare for immobility to be so prolonged that they become permanently stretched.

These findings have negated the long held belief quoted in Smout and Jacoby (1948) as well as by other authorities that nature relies on muscles for support as they exhibit tone, contract and relax and can thus adjust themselves to the varying needs of the body. Indeed it would appear unquestionable that a most vital function of the pelvic fascia is to take the weight of the pelvic and some abdominal organs and this would account for a fact which has exercised me considerably and that is why, if the levatores have such an important role to play in weight bearing, are they such slender sheets of muscle? They are always in exact proportion to the development of the rest of the body musculature, slightly better developed in the athlete and attenuated to a paper thinness in the elderly and debilitated.

/The ....

The strength of fascia however in the paralysed and elderly is not much less than that of an athletic 35 year old male and Gratz (1931) gives figures of 6222 lbs. per sq. inch, 6373 and 7860 for the three categories respectively, which lend support to my contention that the support of the pelvic viscera in health is largely the responsibility of the pelvic fascia. Evidence in support of this theory culled from Comparative Anatomy is given in Section II.

This function of the pelvic fascia leaves the underlying musculature free to perform its own functions efficiently and to remain electrically active at all times. These functions are considered at the end of the section on the Morphology and Functions of the Pelvic Floor on p.96

ii) Allowing gliding of viscera upon one another - (not original)

iii) Discouraging spread of pathology across the fascial barrier of Denonvillier or the recto-vaginal septum (not original).

iv) Perhaps as there is always more fat in the septal layers in women and as this element is liquid and therefore incompressible it may

  a) act to cushion the nerves and vessels from pressure by the uterus during pregnancy

  b) buoy up the pregnant uterus and protect it in a manner similar to that in which the cerebro-spinal fluid supports the brain and spinal cord.

v) It is the vital concern of the septal layers of pelvic fascia to carry and protect all the ducts, visceral vessels, blood and lymphatic, and the autonomic nerves of the pelvis.

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SECTION II

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SECTION TWO.

THE MUSCLES

PART 1.

INTRODUCTION TO MUSCLE SECTION.

Although not strictly accurate it is convenient to refer to the external anal sphincter as part of the pelvic floor for reasons which I hope to make clear in this thesis.

The pelvic floor muscles are unique in that:

1. They show continuous electrical activity when tested by electromyography as established by Floyd and Walls (1953), Taverner and Smiddy (1959), Porter (1962), Parks (1962), Schuster (1968), amongst others.
2. The reaction of degeneration does not follow division of the nerves to the external sphincter.
3. After nerve destruction the tone of the external anal and urethral sphincters gradually returns.
4. Histologically changes do not occur in the paralysed muscles for very long periods of time (2 and 3 were noted by T.R. Elliott (1906). 2, 3, 4 quoted by Hiller (1931) from Westphal) paved the way for promising new electrical treatment of incontinence.
5. In ways which I shall indicate in this section, these muscles are found to be inseparably linked anatomically. Moreover physiological studies show that they act as a functional unit which co-operates with the visceral musculature of the 'tubes' Anson et al (1942) traversing them.
6. Different parts of the striated muscle complex have different functions depending on their relations and attachments but just as we may
   a) encounter parts of the same muscle with antagonistic functions, e.g. inferior constrictor of the pharynx or
   b) synergic co-ordination of a group of muscles as occurs between the extrinsic muscles of the eyeball, or
   c) striated and smooth muscle may act in harmony, e.g. oesophagus so we have in the musculature of the pelvic floor an astonishing complex which combines the principles

illustrated by all the above-mentioned examples. The innervation of these muscles is of extraordinary importance and its peculiarities help to explain some of the special properties which they show.

The adult levatores ani are first described and illustrated and the ways in which the form of the infant pelvis produces differences in the infant muscle will be outlined.

A comparison of descriptions and illustrations of these muscles is then made to show how widely some misconceptions and inaccuracies have been disseminated in Textbooks and the Literature.

The external anal sphincter, which is indivisible from the levatores, will then be described with relevant notes about the infant sphincter. An account of the deep perineal pouch (urogenital diaphragm) musculature and other muscles which act on the urethra is then given and the relationships between them and the levator ani are noted. A correlation between structure and function in relation to the urethra is proposed.

The above descriptions will include morphology of the muscles and variations or references to them. Their gross nerve and blood supply as well as physiological features of special pertinence are also noted.

In order more fully to understand how the pelvic floor muscles come to be arranged and function as they do a brief section on comparative anatomy is interposed.

There follows a short section on the histology of the pelvic floor muscles with special attention to their innervation.

In the final part conclusions concerning the co-ordinated functions of the whole pelvic floor are proposed and are followed by an analysis of the functions of individual components thereof.

The role of the pelvic fascia in enabling these muscles to perform so efficiently is again stressed.

/PART 2. ....

PART 2.

1. THE LEVATORES ANI MUSCLES

a) Definitions

These muscles are subject to great variations but in most cases a distinct separation into pubo-coccygeus and ilio-coccygeus is found, the anterior fibres of the latter lying caudal or superficial to the former as it approaches the midline in 58% of specimens in whom the relationship could be unequivocally demonstrated.

Beneath what may be termed the CRANIAL part of the muscle, shown in Plate 2.4 whose fibres are visible after removal of the superior fascia of the levator ani, CAUDAL fibres forming the bulk of the slender pubo-recto-analis sling are revealed and these have a special anchoring role which I shall describe shortly. Layering of the muscle was first noted by Holl, who is quoted by Uhlenhuth (1953) and Levy (1936) and later this was confirmed by Peter Thompson in Bryce's edition of Quain's Anatomy (1923). The part of the levator which is attached to the bowel wall may be termed 'fixed' whereas the rest may be termed 'FREE'.

Coccygeus fills in the pelvic diaphragm posteriorly and has a triangular form with its apex on the medial aspect of the ischial spine, from which fibres, often strongly tendinous as well as fleshy, radiate to the base formed by the last two pieces of the sacrum and the whole of the coccyx. Caudally it has degenerated to form the sacro-spinous ligament.
Pyriformis closes off the pelvis from the gluteal region behind.

b) Pubo-Coccygeus

The pubo-coccygeus consists of cranial and caudal fibres.

A) Cranial Fibres

i) Bony attachment. The antero-lateral origin or attachment takes three forms - the commonest (73%) and least illustrated may be termed high and as can be seen in Photograph (2.1) arises from the posterior aspect of the

/body ....

body of the pubis and from a gently curved line of attachment which passes upwards and laterally along the posterior aspect of the superior pubic ramus as far as the anterior margin of the obturator foramen.

An intermediate origin is shown in those specimens in which the muscle fibres fall short of the obturator foramen by 1 cm. or more (23%); it is illustrated in Photo 2.2.

The low type (4%) which is favoured by most textbooks, e.g.

Fig. 346 on p. 313 in Gray's Anatomy (1967)
Fig. 576 on p. 645 in Gray's Anatomy (1967)
Fig. 168 on p. in Tobias and Arnold's Man's Anatomy (1967)
Fig. 311 on p. 191 and
Fig. 309 on p. 189 in Lockhart, Hamilton & Fyfe (1959)
Fig. 231 on p. 258 in Cunningham's Manual of Practical Anatomy (1968)
Fig. 20.40 in Section 20.29 of a Companion to Medical Studies (1968)
Fig. 93 on p. 120 in Hamilton's Textbook of Human Anatomy (1956)

and is to be seen in Obstetrical Textbooks as well, e.g. Danforth (1966)

consists of fibres arising only from the back of the body of the pubis and from the tendinous arc of the levator ani as shown in Photo 2.3.

ii) Fascial attachments, form and insertions. These are shown in Plate 2.4 and Fig. 2.5

Cranial fibres which are mainly fleshy, but occasionally tendinous in their upper reaches, also take partial origin from the overlying superior fascia of the levator and from the arcus tendineous of the levator ani as they pass to their insertion or attachments,

/which ....

which are all medially directed.

The insertion of cranial fibres arising from anterior and medial to posterior and lateral is as shown in Fig. 2.5.

In the MALE

(a-b)1) The well known levator glandulae prostatae fibres closely embrace the sides of the prostate as they pass downwards, backwards and medially to join the perineal body. The most medial fibres are separated by very dense superior fascia, which clothes the pubo-prostatic ligaments above, and is in continuity below round the medial free edge of the levator with the inferior fascia. This fascia, as described earlier, joins the superior fascia of the urogenital diaphragm, which closely invests the urethra as it passes from its prostatic to its membranous part. Fibres which join the urethral wall must do so after joining the perineal body. I have not found convincing evidence of 'pubo-urethralis' fibres joining the wall directly either in gross specimens or in histological ones although the evidence of superior fascia of the levator doing so is overwhelming. This finding is contrary to that of Anson (1942), Parks (1958), Kelly (1969) and Kennedy (1946) amongst others, but is supported by Krantz (1951) and Jeffcoate and Roberts (1952). Photo 2.6 shows a parasagittal quadrantic section for orientation. Note prostate and its venous plexus, septum of Denonvillier and behind it part of the rectum. Photo 2.7 shows the same specimen from behind. The flattened superior surface of the bladder, outline of seminal vesicles and prostate and part of the anterior rectal wall can be seen. To the right of this 'block' of tissue is a shadow cast by it onto the levator on the lateral pelvic wall.

/Photo ....

Photo 2.8. The 'block' referred to in Photo 2.7. has now been reflected medially to show levator glandulae prostatae fibres passing round the prostate into the perineal body whilst below these some fibres are joining the rectal wall. Note the superior fascia of the levator has been dissected onto the prostate.

2) Some fibres of the pre-rectal group pass directly to the anterior wall of the ano-rectum both behind the perineal body and just lateral to it. There is an interval of about 1 cm. between the attachments of the medial edge of the levatores to the anterior bowel wall. These fibres are simply a part of the circumferential conjoined longitudinal coat but may exert a more directly elevating effect on the bowel than the other conjoined fibres. These fibres are shown in Photo 2.9.

In Photo 2.9 most of the left half of the prostate and L. vas and seminal vesicle have been removed from a coronally sectioned pelvis. The anterior attachment of the left levator can be seen but on the right the muscle has been detached so is out of position. The fibres which join the anterior wall of the rectum are seen on the left.

3) Varying in different specimens are prerectal fibres which pass downwards either through or around the perineal body to commingle with the deep external sphincter as shown in Photo 2.10 or perhaps, accompanied by caudal puboerecto-analis fibres to ramify on the surface of the external anal sphincter as described earlier.

Photo 2.10 shows a parasagittal section of a 14 week old female foetus with levator fibres joining the external sphincter in front of the bowel.

Muscle fibres which reach the deep and superficial

/perineal ....

perineal pouches arise from the caudal group only - unless they have traversed the perineal body. These fibres are very scanty and are illustrated in Plate 2.67.

In the FEMALE

(a-b) 1) Sphincter vaginae fibres are also found to skirt the urethra (separated by fascia which joins the walls and covers the pubo-vesical/urethral ligaments) and becomes firmly attached to the vaginal wall and perineal body behind the vagina. The crossing fibres of Luschka as described by W. Smith (1923) in the nulliparous female are of very rare occurrence.

Photo 2.11 shows a coronal section in which levator ani fibres appear to join the vaginal wall accompanied by overlying fascia.

Note the caudal fibres of pubo-recto analis lying lateral to the cranial levator ones.

A section of the vaginal wall from this zone of levator attachment is shown in Photo 2.12 which must be reversed to fit and the site from which it was removed appears in Photo 2.13. Histology of this region is of extraordinary interest.

I had expected that either striated and smooth muscle layers, separated by fibrous tissue, would continue in parallel towards the perineal body or that some striated fibres might pass through the fibrous layer and intermingle with the smooth muscle of the vaginal wall. What in fact happens in this case is that smooth muscle from the vaginal wall radiates outwards and upwards to interlace convincingly with the striated muscle of the levator ani. This arrangement would be in keeping with the tendency of the pelvic viscera to send out sprays of smooth muscle from their walls e.g. utero-sacral and lateral ligaments, fibres from uterus to peritoneum, from bladder to pubis, from

/rectum ....

rectum to perineal body and sacrum and the conjoined longitudinal coat-tails.

Photo 2.14 shows the interweaving of striated and smooth muscle fibres very plainly.

The next 3 photos show the intermingling of smooth and striped muscle in the vaginal wall under low, medium and high powers. The specimen is from a newborn female infant.

Photo 2.15 shows the lumen of the vagina on the right. Striated levator fibres on the left are joining the smooth muscle of the vaginal wall in a most convincing fashion. Photo 2.16 shows a medium power view of the junction and Photo 2.17 shows a close up view of the arrangement.

Exceptional attachments of the levator to the vaginal wall was noted in this specimen. Perhaps this is the reason why in this case no sphincter vaginae fibres pass into the perineal body. They continue after an indentation to encircle the rectum as shown in Photo 2.18

2) & 3) Pre-rectal fibres which join the bowel wall and the external sphincter differ in no way from those in the male.

(b-c) Lateral to these are fibres which join the conjoined longitudinal coat of the ano-rectum. Their close proximity is shown in Photo 2.19 and 2.20 under low & high power.

(c-d) More laterally a few fibres which in some represent a cranial part of the pubo-recto-analis sling arise. Photo 2.21 illustrates them.

(d-f) Finally, the most lateral fibres pass to their insertion into the upper stratum of the ano-coccygeal raphe and the coccyx. These (d-f) fibres form the bulk of pubo-coccygeus and have a well defined curved

/posterior ....

posterior edge, beneath which, in many cases, the anterior fibres of ilio-coccygeus may be seen to disappear. Photo 2.22 shows the anterior part of ilio-coccygeus arising from its tendon to the right of the 'high' origin pubo-coccygeus. Bowel fills the lower right field.

B) Caudal fibres

These may be divided into a medially placed pubo-recto-analis sling and, in some cases, fibres which arise more laterally to within ½ cm. of the obturator foramen and then join the intermediate stratum of the ano-coccygeal raphe. Occasionally some of these outer fibres form part of the pubo-recto-analis sling as well. The caudal fibres are only seen when cranial fibres are divided or separated. They are indicated diagrammatically in Fig. 2.23 and are revealed when cranial fibres are parted. Photo 2.24 shows urethra, perineal body and anterior bowel wall in close proximity. To the right cranial fibres have been separated and caudal ones are revealed.

Pubo-recto-analis (P.R.A.)

These fibres which form an important component of the ano-rectal ring closely invest the ano-rectum and upper anal canal. They form the LOWEST FREE PART of the FUNNEL-SHAPED LEVATOR ANI MUSCLE and form a band which is almost at right angles to the rest of the free muscle, so that it faces medially at the sides of the ano-rectal junction and anteriorly behind it, in which position it intermingles with the external anal sphincter. The band lies in continuity with, but is always LATERAL to those cranial fibres which have joined the conjoined longitudinal coat of the bowel.

Its position is indicated by dotted lines in Plate 2.25 which shows the relation of the muscle to the deep external sphincter behind. See also Photos 2.54 and 2.55. Photo 2.26 shows cranial fibres pinned medially and

/laterally ....

laterally. Near the top of the picture the internal urinary meatus is seen surrounded by a cuff of bladder. To the left of this the tendinous origin of this strap muscle can be seen and the fibres can be traced to the bottom of the picture.

Photo 2.27 and 2.28 form a sequence in a coronal specially cut specimen. In Photo 2.27 levator glandulae prostatae fibres and fibres which join the anterior rectal wall are visible. Note the free medial edge of the levator beyond which can be seen the dense superior fascia which is visible to the right and part of which passes round that edge to cover the undersurface of the muscle. Just lateral to the fibres which join the bowel wall the pubo-recto-analis can be seen, roughened where it has been separated from the pudendal canal, which is on the left just medial to obturator internus.

Photo 2.28 is the same scene viewed from a more posterior angle. The cut bowel is now easily recognised as well as the perineal flexure (ano-rectal angle).

Just lateral to the cranial levator fibres which have joined the bowel wall is the pubo-recto-analis sling.

Photo 2.29 shows a coronal anterior quarter of a female pelvis. Above is part of the bladder, centrally is vaginal wall with a small portion of the urethra traversing it below. Close to the vaginal wall on each side are the pubo-recto-anales on the left appearing more flattened and on the right oval - above each cranial levator fibres, surmounted by fascia, can be distinguished.

Posteriorly P.R.A. becomes inextricably blended with fibres of the external anal sphincter in which its posterior fibres lose their identity. A convenient name for this admixed unit is the 'sling complex'. As Goligher et al (1955) have indicated the sling may be formed predominantly by the pubo-recto-analis or the external sphincter. I have found that the external sphincter component usually

/predominates. ....

predominates. This sling has been dissected out and appears in Photo 2.30.

Posteriorly the sling complex is attached to the tip of the coccyx by interlacing bands which form part of the intermediate stratum of the ano-coccygeal raphe. The other part is formed by caudal fibres of ilio-coccygeus when these are present.

Relations of the Pubo-Recto-Analis (P.R.A.)

This complicated little strap of muscle is conveniently described in three parts which depend on the direction the muscle fibres follow. The first part passes downwards and backwards, the second backwards and laterally, and the third medially and backwards - the predominant direction is stated first in each instance.

The first part passes from its origin on the back of the body of the pubis and superior fascia of the urogenital diaphragm at a lower level, downwards and backwards to the point at which it becomes related to the wall of the anterior end of the pudendal canal. The inferior fascia of the muscle in this part of its course blends with the fascia covering the urogenital diaphragm (deep perineal pouch) this being derived via the pudendal canal from the obturator fascia which lies anterior and below it. It is related posteriorly to cranial pre-rectal fibres of pubo-coccygeus, from which, in some specimens, I was unable to separate it.

Medially it helps form the medial free border of the levator ani and is connected by its fascia to the prostatic plexus of veins which lie immediately below and behind the pubic symphysis and the arcuate sub-pubic ligament and is connected with the dorsal vein of penis/clitoris and receives pudendal and obturator contributions.

The second part is angled fairly sharply backwards and its outer fibres adhere to the upper part of the wall

/of ....

of the pudendal canal anteriorly to a point approximately 2.5 cm. anterior to the ischial spine in the adult. Branches of the internal pudendal vessels and perineal nerve pass through the wall of the canal and supply pubo-recto-analis and adjacent levator fibres and are partly the cause of this attachment.

In this section the pudendal canal and contents with some of the lowest fibres of obturator internus lie laterally as seen in Plate 2.69 and Photo 2.31. Photo 2.31 shows the levator muscle detached and reflected medially so that to the left is obturator internus - in the middle is the pudendal canal seen from above with the internal pudendal artery and some of its branches in the deep perineal pouch on view and, to the right, is the thickening which is the pubo-recto-analis attached to the undersurface of the medial portion of the levator in front, whilst medially it passes inferior to the rest of the free cranial levator fibres and is separated from the bowel wall only by pubococcygeal fibres joining the bowel wall. This part passes backwards and slightly laterally forming an angle with the downward and medially coursing cranial ones as shown in Plate 2.69. This relationship to the pudendal canal is one of the factors which makes it so difficult to demonstrate a neat muscle band as fascial adhesions tend to obscure the fine fibres which are easily damaged.

The third part arches gently backwards and medially to form the lowest part of the funnel-shaped levator ani forming with cranial fibres when present a horseshoe round the ano-rectal junction and upper part of the anal canal. In this region it is closely related to the external anal sphincter. It lies either immediately above and blends with the external sphincter or it is cradled by the external sphincter and this latter relationship nearly always obtains posteriorly. Occasionally some of the outermost pubo-recto-analis fibres spray downwards and

/backwards ....

backwards from this third part to join the external sphincter. Such a fine leash of muscle fibres may reach the anal verge.

A fairly constant slip of muscle arises from the pudendal canal wall in relation to the beginning of the third part of the pubo-recto-analis and this joins the external anal sphincter posteriorly tending to travel back with the sling fibres.

As the pubo-recto-analis band completed its posterior horseshoe curve in its third part it is frequently partly obscured from view by

a) fibres of the levator ani which travel obliquely downward, and backwards over it to interlace with fibres of the external sphincter

b) fibres of the external sphincter overlapping it and commingling with fibres of the levator ani as shown in Photo 2.32. The forceps holds up some external sphincter fibres to reveal levator ones interweaving with external sphincter ones.

These arrangements coupled with its caudal position account for the difficulties encountered in tracing the muscle band.

Certain facts about the P.R.A. have not received sufficient emphasis in the past.

1. The natural division of the muscle into three parts depending on the direction of the fibres.
2. It is in the third part that it forms a 'sling complex' with the external anal sphincter.
3. As the muscle sweeps round the ano-rectum and upper anal canal its most medial fibres are intimately related to the conjoined longitudinal coat of the bowel to which, in occasional specimens, it appears to contribute.
4. It has interlaced crossing fibres which in company with external sphincter fibres mostly join the middle

/stratum ....

stratum of the ano-coccygeal raphe. The raphe forms a firm, tethering fibro-fascial band between the bowel wall and the coccyx and part of it is shown histologically in Photo 2.33. It is possible that a few interlacing fibres continue into annular sphincter fibres and so reach the perineal body, as suggested by Courtney (quoted by Parks 1958).

5. It lies below but in contiguity with the free cranial fibres of the levator and is always LATERAL to or outside the cranial fibres which join the conjoined longitudinal coat as illustrated.
6. In those cases in which the sling is cradled by the external sphincter conjoined longitudinal 'coat tails' pass through the lower part of the 'sling complex' into the external sphincter as shown later.

These tethering and midline attachments and the interlacing with the external sphincter fibres provide two-way anchoring of the bowel in this area and allow the pubo-recto-analis muscle to get a mechanical purchase on the bowel wall out of all proportion to the size of the muscle band itself.

The Nature of the Pubo-Recto-Analis

For the following reasons I am unable to accept this muscle as anything more than a modified and specialised portion of the levator ani/external anal sphincter muscle complex which, though not an embryological unit, becomes an anatomical and functional one:

1. The muscle is so closely related to the cranial part of the pubo-coccygeus muscle that in some cases I have been unable by any means to separate it from the overlying fibres to which it is related.
2. The nerve to levator ani passes through the anterior part of pubo-coccygeus to supply the muscle, which suggests a common anterior origin for the muscle.

3. It is inseparable from the external anal sphincter behind.
4. Branches of the perineal nerve inferiorly and anteriorly supply the sling complex and twigs of the inferior haemorrhoidal nerve which pass through the space between the sling complex and lower strata of the raphe thus reach it posteriorly.
5. Because of the way in which the levator ani fits into and interlaces with the boat-shaped elliptical external sphincter closely co-ordinated functions for these muscles must be postulated.

I have never seen sufficient pubo-recto-analis fibres (as shown in Plate 2.69) enter the deep pouch by passing through the superior fascia of the urogenital diaphragm to make it seem conceivable that Parks' (1953) suggestion that this muscle arises in common with the muscles in the deep pouch, thus forming originally a sling round the cloaca, could be correct. Courtney's figure of 8 hypothesis has been referred to but does not account for the relatively dense upper layer of the urogenital diaphragm intervening between the pubo-recto-analis and deep pouch muscles and this feature is clearly shown in Plate 2.69 and Photo 2.77. It would appear likely that the innervation of these pelvic floor muscles is the key to their mysterious activity.

c) Ilio-Coccygeus

This muscle varies greatly in size and definition. Tendinous fibres may be admixed with it and may completely replace it. This muscle arises at a varying level from the lateral pelvic wall from the region of the obturator foramen anteriorly as far back as the ischial spine posteriorly. It arises from its own tendon which extends as an aponeurotic sheet up to the brim of the lesser pelvis. This aponeurosis can be separated with care from the underlying fascia on obturator internus. In 2 cases

/a ....

a fleshy slip arising behind the obturator foramen was noted. One of them is shown in Photo 2.34 which also shows ilio-coccygeal fibres slipping caudal to pubo-coccygeal ones.

When present the arcus tendineus of the levator ani gives rise to some of the fibres of ilio-coccygeus and occasionally this arcus, as though pulled taut, may be sited a few millimetres medial to the aponeurosis so that a small crescentic pocket is created known as the hiatus of Schwalbe which overlies the covering of obturator internus. From their origin the fibres sweep downwards and medially the most posterior gaining attachment to the sides of the tip of the coccyx posterior to the pubo-coccygeus whereas the anterior fibres pass in caudal to (58%) or parallel with (39%) the fibres of pubo-coccygeus to join either the middle strata of the ano-coccygeal raphe or the upper stratum, there interlacing with their fellows from the opposite side.

In 36 specimens in whom the relationship of ilio-coccygeus could be clearly defined in 21 (58.3%) ilio-fibres passed caudal to pubo-coccygeus; in 14 (38.9%) they lay in the same plane and in 1 case (2.8%), which must resemble a specimen in the Royal Australasian College (Magnus 1969), was ilio-definitely cranial to pubo-coccygeus.

In 2 specimens ilio-sacralis muscle was seen passing from the ischial spine to the sacrum behind coccygeus. Is this perhaps a reminder of the exclusion of coccygeus from the pelvis in some primates?

In all cases, except one, apart from minor variations, the pattern of the levator ani muscles on each side of the pelvis was symmetrical. In one case on the right side a low origin and pronounced arcus tendinous was present whereas on the left there was a high origin and the arcus tendinous was but faintly marked. However, insertions in this case followed the usual arrangement.

2. INFANT ANATOMY

Some points relating to the anatomy of the pelvic basin in

/pre-natal ....

pre-natal and early post-natal stages deserve emphasis in relation to the surgery of the infant pelvis and are mainly derived from Reynolds (1945) and Morton (1942), some of whose observations I have confirmed and supplemented with a few of my own. The infant pelvic basin has the following features:

1. It is very much smaller in proportion to the whole body than that of the adult; the cavity is funnel-shaped
2. The sacrum is narrow and straight or gently curved with an ill-defined promontory
3. The coccyx is proportionately better developed than in the adult
4. The ischial spines and tuberosities of each side converge on one another
5. The slender pubic bones exhibit a narrow pubic arch.

The pelvis thus is narrow, relatively deep and reduced in all dimensions so that the pelvic viscera fill, and indeed overflow, their confines. The close proximity of the ischial tuberosities to each other results in the bulky medial portions of gluteus maximus, arising from the sacro-tuberous ligament, closing in upon each side of the external sphincter thus narrowing the ischio-rectal fossae as shown in Fig. 1.17.

Levatores Ani

The parts of the levator ani, including pubo-recto-analis, are the same as those described in the adult with variations especially of ilio-coccygeus being notable. Coccygeus is large and fleshy in most instances.

As a result of the pelvic configuration

a) the cone-shaped levator fibres incline more steeply as they pass from their origin to their insertions as shown in Figs 2.37 and 2.38. Fig 2.37 is diagrammatic and shows too many fibres joining the perineal body. The pelvis of an adolescent is shown on the right to show how dramatically the distance between the pubis and coccyx has increased.
In Fig. 2.38 outlines of the pelves of male and female premature infants illustrate their conformation. In the male their proportions are such that levator fibres cannot be drawn in,

/as ....

as they are in the female.

b) the rectum and vagina in the female and the rectum and prostate in the male appear to fill the pelvic cavity (see Fig. 2.39) and these factors, in conjunction with fascial and muscular attachments similar to those described in the adult, make the ano-rectal junction extremely difficult to view from above. For this reason the sacro-abdomino-perineal approach fulfils exposure requirements of this protected region.

The levatores in the infant are paper thin and transparent to light except antero-medially, where caudal fibres of the P.R.A. thicken the muscle mass as shown in Photo 2.40. The right levator ani muscle is seen from inside the pelvis with transillumination indicating the texture of the posterior part of the muscle. Photo 2.41 shows the outside of the right levator ani muscle of the same newborn infant. The clearly defined strap of P.R.A. can be seen below and medially. Behind it is blending with the external sphincter.

Plate 2.25 is a semi-diagrammatic representation of the P.R.A. and sling complex in the infant.

Photo 2.42 shows an almost coronal section of the anal canal of an 8 week old female embryo. Note levator fibres joining the conjoined coat and P.R.A. fibres fitting medial to, and blending with, the external anal sphincter. Above is the uro-genital septum containing the mesonephric and paramesonephric ducts. Obturator internus is seen on each side of the picture.

Photo 2.43 shows the uro-genital septum in a slightly caudal plane after the paramesonephric ducts have fused. P.R.A. has the three parts already described. Interlacement with the external anal sphincter follows the same pattern as that shown in the adult but the angle and sling complex is at a lower level because of the shortness of the anal canal.

3. BLOOD SUPPLY

Arteries to the levator ani come from the internal pudendal, obturator, middle rectal, inferior vesical and median sacral arteries. Photo 2.35 shows a branch from the internal pudendal artery in the pudendal canal, which traverses the levator and supplies twigs to

/the ....

the bowel wall. Further anteriorly sphincteric twigs pass to the second part of the pubo-recto-analis and external sphincter as shown in Plate 2.69. Very constant branches of the obturator artery pass superficially and through the substance of the levator to end by anastomosing with vessels in the deep perineal pouch, and with urethral and prostatic branches as well.

In 3 specimens a branch of the internal iliac travelled over the upper surface of the levator just lateral to the viscera and in one of these had the relationship to the 'low' origin, tendinous arc shown in Photo 2.36 before it passed into the deep perineal pouch.

4. GROSS NERVE SUPPLY OF THE LEVATOR ANI

a) The nerve which carries the main supply to the levator is found on the upper surface of the muscle under the superior fascia of the levator. It lies in the position indicated in Plate 2.4 and arises by twigs usually from the anterior primary rami of S3 and 4 in close association with the nervi erigentes.

These fibres pass from Waldeyer's layer through the superior fascia of the levator.

A communication between the nerve to levator ani and a long visceral branch of S4 is illustrated in Fig. 2.44.

In the chimpanzee and baboon it is noteworthy that muscular and visceral branches come off a common stem in a very arbitrary fashion. This seems occasionally to obtain in man as well.

Photo 2.45 shows the nerve to levator arising from S3 and 4. It has rather a spread out form in this specimen.

In Photo 2.46 nerve fibres to the bowel wall and passing from left to right supplying the levator ani are seen in a new born infant. Bowel has been divided and reflected proximally and distally. Arcus tendineus of levator ani is clearly visible passing towards the lower border of the pubic symphysis.

b) The perineal branch of 4th sacral nerve on its lower aspect is shown in Figs 2.62 and 2.63.

c) Twigs from the inferior haemorrhoidal and perineal branches of the pudendal nerve supply its lower aspect. The latter are termed sphincteric branches and are shown in Plate 2.69.

PART 3.

1. COMPARISON OF TEXTBOOK DESCRIPTIONS AND ILLUSTRATIONS OF THE LEVATOR ANI MUSCLE AND ITS PUBO-RECTALIS COMPONENT

An attempt is made in this section to augment the excellent review of ano-rectal musculature set out by Levy in 1936 with accounts of the levatores ani as given by representative authors of textbooks of the 17th, 18th, 19th and 20th centuries.

Levy quotes Galen (AD 129-200) as giving in his "De Sedis Musculis" a fair description of the external anal sphincter and describing 'two other membranous muscles which are located above the round muscle. Inside of the pubis and laterally towards the sacrum and on both sides they are inserted obliquely and draw the rectum upward with vehement desire and efforts to defaecate. It draws the same farther out, propelling and everting the same'. He reprints the first extanct illustration of the levatores which appears in "De Humani Corporis Fabrica" (Andreas Vesalius and John Calcar of Clive) and this shows the relationship of the muscles to the external sphincter and gives a sketchy impression of an enucleation specimen. He also quotes from Cowper (1694) who disagrees in agreeably emphatic terms with the numerous subdivisions of ano-rectal musculature proposed by Riolan (1580-1657).

William Cheseldon in "The Anatomy of the Human Body" (1732, 1956) says that Dr. Douglas (doubtless of Pouch fame) described 2 pairs of muscles whereas Dr. Cowper reported 1 muscle only which arises from os ischii, pubis and sacrum within the pelvis and is inserted round the lower end of the rectum intestinum. To Dr. Douglas the discovery of the sphincter vaginae portion of the levator is also accredited. Until that time the name was applied only to bulbo-spongiosus muscle.

William Northcote in 1776 in his 'Anatomy of the Human Body - On an entire New Plan - in a Method very different from all Anatomical Writers' repeats almost verbatim Cheseldon's account but adds the function of elevating the anus lest the faeces be burdensome to the sphincter and of pressing the prostate and seminal vesicles in order to promote emission of the seminal juices during coition.

/Charles ....

Charles Bell in the 6th edition of the 'Anatomy and Physiology of the Human Body' by John and Charles Bell (1826) introduces the important concept of the levator ani having a funnel or inverted cone shape 'growing gradually smaller as it goes down to surround the anus'. He also states that it is mixed with the sphincter ani muscle and advances views on function which will be quoted later. Despite his major contribution he considered the levatores to be one muscle and states erroneously that the whole bladder is surrounded and covered by this muscle.

Cruveillier in 1843 was the first, as noted by Levy (1936), to remark fibres of the levator joining the rectum whilst Kohlrausch in 1854 confirmed this observation. Beraud in 1858 clearly described some of the terminations of the conjoined longitudinal coat and Roux in 1881 showed terminations in histological sections.

Layering of the levatores ani muscles was first noted by Holl (1897) who is quoted by Levy (1936) and Uhlenhuth (1953), and later this was confirmed by Peter Thompson who is quoted in Bryce's edition of Quain's Anatomy (1923). This textbook is the only one in which the common 'high' origin of the levator ani muscle is accurately described and in which a reasonable description of the pubo-rectalis is given although no text illustrates and labels a 'high' origin.

Considering now current 20th century textbooks of Anatomy we find that: In Gynaecological and Obstretric Anatomy by Smout and Jacoby (1947), these authors describe the muscle as arising from the posterior (pelvic) aspect of the body of the pubis, from the arcus tendineus fasciae pelvis (white line of the pelvic fascia) and from the pelvic aspect of the ischial spine. The insertion is correctly given in essentials. The pubo-rectalis component is described as the part joining the anal canal. (The illustration shows a greatly exaggerated hiatus urogenitalis).

Hamilton's Textbook of Human Anatomy (1956) describes the deeper (upper) fibres of pubo-coccygeus of each side uniting immediately behind the ano-rectal junction to form a loop whereas the more superficial (lower) fibres join the ano-coccygeal raphe. Hamilton also states that the levator arises from the 'tendinous arch of the pelvic fascia.'

/Lockhart ....

Lockhart (1959) gives a 'low' origin in illustrations and his text states that the muscle arises from the tendinous arch of the levator ani. Although saying that the 'tendinous arch of the levator' is not to be confused with the 'tendinous arch of the pelvic fascia' which is vaguely described, in figs 309 & 311 the 'tendinous arch of the levator' is labelled as the 'tendinous arch of the pelvic fascia'. In this case the two were doubtless coincident. The bony attachments are shown only to the body of the pubis and ischial spine. His illustrations are otherwise of a very high order of excellence.

Tobias and Arnold in Man's Anatomy (1967) in Fig. 167 label a wide puborectalis inserted into the sides of the ano-rectal junction and a pubo-rectal sling arising between this and iliococcygeus which is not labelled. In the sagittal view of Fig. 168 the same relationship of the puborectal sling is to be noted as are the absence of any relationship between the external anal sphincter and pubo-recto-analis. The modern low origin of levator ani is illustrated. These diagrams have, I think, been inspired by those of Milligan and Morgan (1934).

Grant (1965) in Fig. 346 on p. 313 shows a 'low' origin of the muscles. Although he suggests that the sling is caudal he does not describe it clearly despite his fine diagram (Fig. 370) which Milligan and Morgan adopted when they introduced their excellent ano-rectal ring concept in 1934. Even Frazer (1965) shows a 'low' origin and attachments of the levator ani.

In Gray (1967) the muscle is illustrated and described with a 'low' origin thus:

> 'It arises, in front, from the pelvic surface of the body of the pubis lateral to the symphysis; behind, from the inner surface of the spine of the ischium and between these two points, from the obturator fascia.'

The puborectalis is illustrated in a caudal plane but is described in rather general terms and a contribution from it to the conjoined longitudinal is remarked without a distinction being drawn between cranial and caudal fibres. The osteology section also shows only the limited attachment of the levator to the pubic bone and ischial spine.

/Goligher, ...

Golighher, J.C. (1967) Surgery of the Anus, Rectum and Colon, states that 'pubo-coccygeus arises from the back of the pubis and anterior part of the obturator fascia and is directed almost horizontally backwards along the side of the lower part of the rectum as a flat band which lies superior to the innermost fibres of ilio-coccygeus (spelt ileo) to fuse with its fellow to constitute a broad fibrous band lying on the ano-coccygeal raphe formed by the ilio-coccygeus. This band is continued up the front of the coccyx to be inserted into the anterior aspect of the 1st piece of the coccyx and last piece of the sacrum. This suggests a 'low' origin muscle. His illustration taken from C. Naunton Morgan (1949) shows a muscle posteriorly which is clearly recto-coccygeus lying above the ano-coccygeal raphe. This drawing shows an unduly wide gap between the urethra and rectum and a very exaggerated one between ilio- and ischio-coccygeus.

In Cunningham's Manual (1968) and Textbook the muscle is described and its attachment to bone illustrated in its 'low' form. It is said to arise between two bony points from the 'tendinous arch of the obturator fascia'. Pubo-rectalis is described as a muscle which arises from the pubic bone as a separate bundle which passes posteriorly on the upper surface of the other fibres of the levator ani for the formation of a U-shaped loop. These must have been cranial sling fibres in this instance.

Passmore and Robson's 'A Companion to Medical Studies', (1968) which is a revolutionary and most modern textbook, makes no mention of levator fibres joining the wall of the ano-rectum, nor are these illustrated - in fact in Fig. 20.41 on p. 20.31 an ominous gap which is quite fictitious is shown on each side of the ano-rectum. The pubo-rectalis is illustrated and described as lying between fibres passing to the perineal body and those passing to the ano-coccygeal raphe and its usual anterior attachment is not shown. Fig. 20:40 on P. 20:29 illustrates the 'low' origin of the muscle.

Kerreman's (1969) also subscribes to the 'low origin' of the levator ani.

Gardner et al (1969) in 'Anatomy' also describe and illustrate the

/pubo-coccygeus ....

pubo-coccygeus as arising from the back of the body of the pubis and from 'the tendinous arch of the levator when this arch is present'. Their pubo-rectalis is illustrated in the correct plane and is described as passing backwards to unite with a corresponding part of the contralateral muscle to form a muscular sling behind the ano-rectal junction. However, they describe it as a conspicuous part of the levator ani muscle despite its blending with external sphincter fibres, and in the diagram of the muscles of the pelvic diaphragm from below based on those of Milligan and Morgan (1934), the pubo-rectalis is shown between ilio and pubo-coccygeus - the extent of the perineal body in the female is grossly exaggerated and none of pubo-coccygeus is shown actually reaching the coccyx. Furthermore the parts shown are hard to correlate with the diagram of the muscles from their pelvic aspect and in this a very wide arcus tendineus of levator ani reaches a curiously positioned ischial spine. 'Conspicuous' I believe is the last adjective which can be applied to the pubo-recto-analis. In my early searches for it I had moments when I was sure it would turn out to be a 'boojum'.

2. COMPARISON OF DESCRIPTIONS IN RECENT LITERATURE

The diagrams which appear in otherwise excellent articles on physiological (electromyographic, pressure studies and cineradiography) topics in relation to the pelvic floor are frequently inaccurate and often show surprising omissions. For example Porter (1962) does not mention the conjoined longitudinal coat and his diagrams do not show it. In the same article the external sphincter is not clearly represented and the pubo-rectalis sling is shown outside the external sphincter whereas, as noted earlier, only a few fibres pass from the pubo-recto-analis to intermingle with external sphincter fibres superficially and most lie just above and in continuity with it or are medial to it as already described. Duthie (1969) in his review of the aetiology and treatment of incontinence shows very vague pictures of muscles especially in Fig. 1 where the external sphincter is very high above the skin - pubo-rectalis is shown as a separate entity and the conjoined coat is not suggested.

/Naunton ....

Naunton Morgan (1949) also described the pubo-coccygeus as arising from the white line as far as the obturator canal. Fig. 4 is the one reproduced by Goligher, which received comment on p. 47. I disagree with his objection to the form of the levator being 'funnel-shaped' especially when one considers that the lowest part of the funnel is the pubo-recto-analis and conjoined coat. The fibres of pubo-coccygeus, although having an antero-posterior direction, incline downwards as well. Naunton Morgan (1949) was the first to describe the anterior extension of the ischio-rectal space above the urogenital diaphragm and to explain the horseshoe form of some ischio-rectal abscesses.

My description of the levator ani differs from that of Parks (1958) in that my cranial layer includes all of the muscle which can be seen from above whereas his cranial layer includes only those fibres which join the conjoined longitudinal coat.

The weakness of John X. Louw's (1962) article is his failure to recognise the importance of the fibrous and fascial components of the pelvic floor. The diagrams are out of proportion and in some cases inaccurate as well.

The arrangement of the autonomic nerves is sketchy. Many authorities including Fowler have disproved the existence of a suspensory muscle of the anal mucosa from longitudinal 'coat-tails' gaining attachment to Hilton's 'white line'. The fibro-muscular septum of the ischio-rectal fossa is by no means a constant feature. His description of the 'coat-tails' is inadequate.

On balance I think that his functional division is not justifiable, though the general arrangement of cranial (diaphragmatic) and caudal (sling) fibres, is incontrovertible.

Walls' comment on the pubo-rectalis is included in Section IV.

Irwin (1969) in describing his successful treatment of a case of pelvi-rectal fistula by a sacral approach shows a waisted muscle which he calls ano-coccygeus in Fig. 4, which also shows an entirely cranial pubo-rectalis sling passing to an attachment on the coccyx without the intermediary of the raphe.

Hardcastle and Porter (1969) say that the powerful pubo-rectalis sling maintains the anorectal angle during periods of stress. No mention is made of the related external sphincter.

Although Brossy (1959) calls the pubo-rectalis sling of the levator the most important single factor in faecal control, his illustration of this entity is far from satisfactory, which is what one would expect, as no one who has seen this muscle would place so much reliance on it alone.

PART 4.

THE EXTERNAL ANAL SPHINCTER

Discussion

This 'whorled' muscle mass may assume a great variety of forms, all of which have been described by the combined efforts of generations of tenacious anatomists. It may project to a lower level than normal when the pelvic floor is lax. The muscle complex formed by the levator ani which is funnel-shaped and fits into the boat-shaped external sphincter, with which it is indissolubly united, is illustrated in Figs. 2.47 and Photos 2.48 and 2.49.

Photo 2.49 shows a familiar view of the musculature. The elliptical conformation of the external sphincter can be seen. The pubo-coccygeus blending with it is suggested. The right superficial transverse perineal muscle is well shown to the left of the picture and the detached ano-coccygeal raphe is in the lower part of the field.

The external sphincters of urethra and ano-rectum, which originated as cloacal sphincteric musculature, and the levatores ani, which developed from sacral somites, are unique in that they are the only skeletal striated muscles in the body which are not in motion and yet are constantly vigilant as proved by electromyography (Floyd and Walls (1953), Basmajian (1962), Taverner and Smiddy (1959) and Porter (1962)). The continuous electrical activity recorded from the external sphincter and pubo-recto-analis clearly have a role to play in maintaining the antero-posterior slit form of the anal canal whereas the sealing together of the mucosal walls is achieved by a combination of factors which will be referred to later.

The external sphincter is composed of both red and white fibres, the

/red ....

red fibres being rich in sarcoplasm. The red 'slow' Type 1 fibres show sustained activity and metabolism is mainly of the oxidative type conducted through the Kreb's Cycle whereas the white 'fast' Type II fibres produce rapid activity and metabolism is conducted through the Emden-Meyerhof glycolytic pathway. The type of muscle fibre, according to the researches of Buller and Eccles (1960), Dubowitz (1967) and others, depends on its innervation, as if nerve fibres from a 'slow' muscle, like soleus, are transplanted to those of a 'fast' muscle, e.g. flexor hallucis longus - the muscle fibres take on the histochemical pattern of the slow muscle fibres because enzymes associated with the metabolic pathway of the donor muscles are found by selective staining to be present. Basmajian (1962) quotes Giovane (1959) as reporting a larger proportion of red than of white fibres in the external sphincter. We intend to investigate this in the immediate future.

Of extreme interest is the work of Kerreman's (1969) in this field which has just come to hand. He reports

1. Large sized fibres with histochemical properties of 'white' fast (Type II) fibres. These are involved in phasic reflexes as outlined in Section V.
2. Very small fibres with properties of 'red' slow (Type I) fibres. These take part in the tonic reflexes outlined in Section V.
3. Middle-sized fibres which 'resemble the red fibres in feature and in intensity of reaction, although they have mixed enzymatic properties'.

The middle sized fibres are only found in the pubo-rectalis and deep part of the external sphincter - they are perhaps of significance then in distinguishing the 'sling complex' as a definite entity.

Although the muscle fibres closely resemble in type those found in other sphincteric positions, e.g. orbicularis oris and oculi, the pattern of electrical activity much more closely resembles vigorous skeletal muscle, e.g. soleus as considered in Section 4.

Levy (1936) in his review of work on the ano-rectal musculature shows that Galen (129-200 AD) described the external sphincter as round

/but ....

but that Cowper corrected this when he described it as an 'oblong oval' in Myotomia Reformata in 1694. Santorini was the first to subdivide the sphincter into three parts and this interpretation has been maintained by Milligan et al (1948) but denied by Fowler (1963) and Goligher et al (1967) and conceded to be only occasionally present by Walls (1963).

The parts of the external sphincter are in continuity with each other and, because they interlace with the levator ani muscle, need only be subdivided for purposes of descriptive convenience. Because of the variations so fully investigated by Hiller (1959), Gorsch (1962), and Fowler (1963) and corroborated by the ano-rectal sections of Walls (1963) and my own findings, subdivisions are only recognisable in a few cases and the names apply simply to the three regions lower, middle and upper of the external sphincter.

1. Problems in Dissection

Difficulties in dissection of this region include the abundant fat of the ischiorectal fossa, which is traversed by numerous fibrous septa. These join the highly adherent anal fascia forming the epimysial sheath of the external anal sphincter which is continuous above with the inferior fascia of the levator. In this connection I have in three specimens found a reflection of the fascia over obturator internus, sited above and parallel with the superior fascia of the urogenital diaphragm, arch across to join the anal fascia as it is joined by the inferior fascia of the levator. In one specimen it was located above the anterior third of the urogenital diaphragm and had a curved edge with its concavity directed downwards and backwards. This must correspond with Elliot Smith's (1908) 'lamina terminalis fossae ischiorectalis', which is nicely illustrated by Barnes (1921). It does not cover a sufficient area to detract from the truism that the fusion of the inferior fascia of the levator with the obturator fascia marks the apex of the ischio-rectal fossa. The relationship serves further to bind the muscles to each other. Many of the fibrous septa conceal neuro-vascular bundles, which traverse the fossa from their parent stems, and supply the perineal skin, musculature and the

/lining ....

lining of the canal of the ano-rectum. The lower fibres of the external sphincter are of extremely fine calibre and the spraying conjoined longitudinal 'coat-tails', which pass between these bundles, and between higher ones, makes tracing them extremely time-consuming. Finally there are the decussations and interlacing of the external sphincter with the levator ani described in Part 2.

Post-mortem material is often even more difficult to dissect as the fat and fascia adhere firmly to the flaccid muscle.

2. <u>General Considerations in Relation to Attachments and Form.</u>

A. Many external anal sphincter fibres are attached anteriorly to the perineal body and in relation to this attachment a few may continue into the bulbo-spongiosus of the same or the opposite side and/or into the superficial or deep transverse perineal musculature of the same or the opposite side, via the former reaching the ramus of the ischium and the perineal membrane. In view of the paucity of these connections with superficial and deep pouch musculature, reflex activity based on the common origin of these muscles, probably accounts for the fact that contraction or relaxation of one group may be accompanied by similar activity of the other.

B. The relationship to the levator ani is a very intimate one and pertains between:

a) cranial pre-rectal fibres of levator ani

b) <u>free</u> caudal para- and post-rectal fibres of levator which pass down lateral to pubo-recto-analis as previously described.

c) a few superficially placed fibres of the pubo-recto-analis first and second part and the whole of the third part which is intimately intermingled with the external sphincter

d) the conjoined longitudinal 'coat-tails', partly formed by the levator and its superior fascia which pass out through all regions of the external sphincter.

/C. ....

C. The binding of the external sphincter to the wall of the ano-rectum is achieved as noted by the medium of the conjoined longitudinal 'coat tails' which are illustrated by Plate 2.50 and Photo 2.51. Plate 2.50 diagrammatically illustrates the anterior half of a coronally sectioned female neonate. The pubo-recto-analis is depicted as thicker than it really is.

Photo 2.51 is of a transversely sectioned five month old female foetus. Part of the lumen of the anal canal is to the left of the picture. The circular and longitudinal smooth coats are seen. 'Coat-tails' passing between the striated external sphincter can be made out.

D. Many external anal sphincter fibres are attached posteriorly to the lower strata of the ano-coccygeal raphe and to the tip, back and sides of the coccyx.

Hiller describes one variation which I have not seen, namely absence of any posterior attachment of the external sphincter to the coccyx.

Despite variations the following I have found to be valid in dissecting room and post-mortem material.

3. Subcutaneous External Sphincter

This has an elliptical form and is especially well demonstrated under anaesthesia when its altered relationship to the internal anal sphincter has been well documented by Goligher (1955) and Fowler (1963). It is well defined in post-mortem material but its fine annular and antero-posterior muscle bundles broken up by numerous 'coat-tail' terminations of the conjoined longitudinal coat fastening it to the skin of the anal verge make its dissection laborious in the cadaver. Anteriorly in some specimens antero-posterior fibres, which have passed from the raphe and coccyx behind to the perineal body in front extend to join the raphe or bulbo-spongiosus and in these cases a small tunnel can be created deep to these fibres, which can be used when a gracilis sling or other muscle implant is employed to encircle the anal canal (Loygue and Dubois (1964)

/and ....

and Pickrell (1959)). Despite Fowler's (1963) arguments it, combined with conjoined coat-tails, probably produces some wrinkling of the skin of the anal verge, the former perhaps deserving to be termed 'corrugator cutis' as suggested by Louw (1962).

Photo 2.52 shows the form of the subcutaneous part of the sphincter in a transverse section of a seven month old female foetus. The elliptical form of the muscle will be noted and its penetration by numerous coat-tails. The section shows gluteus maximus on the right because the hip joints were unevenly flexed. The anal canal is slit like in form and is not sectioned absolutely at right angles.

Above the subcutaneous sphincter fibres are quite inseparable from the superficial sphincter and the subcutaneous part is named because of its close relationship to the skin.

Either its upper limit or the lower limit of the superficial part form the lower margin of the anal intermuscular depression, which intervenes between striated external sphincter and smooth muscle internal sphincter. It is illustrated in Plate 2.49.

4. Superficial External Sphincter

This has a prominent elliptical conformation in infants, children and healthy adults. In the elderly, and after wasting diseases, it is far less prominent and in some cases becomes grossly attenuated. It consists largely of antero-posterior fibres passing from the perineal body in front to the lower strata of the ano-coccygeal raphe and coccyx behind but a number of circular fibres are also present. Many of these antero-posterior fibres are attached to the sides and back of the coccyx behind and anteriorly occasional slips join bulbospongiosus or the superficial transverse perineal muscle of the same or the opposite side as Photo 2.53 illustrates. This is of the same specimen as Photo 2.52 at the level of the lower border of the superficial transverse perineal muscles. Note in this and in Photo 2.54 the increase in width of muscle behind the anal canal as fibres pass into the raphe. Many annular fibres can be seen.

/The ....

The thickness of the conjoined longitudinal coat is striking.

Photo 2.54, which is just above Photo 2.53 and of the same specimen, shows the superficial transverse perineal muscles passing medially from each side to the perineal body. Note the attachment of the longitudinal coat of the anal canal to the perineal body. Behind the sling complex should just be visible. Superficial fibres in some specimens become attached to the perineal membrane.

Depending on the development of the musculature the superficial fibres lie either, lateral to and tending to cradle the 'sling' formed by pubo-recto-analis and the external sphincter, or, when the muscle mass has dwindled, it lies immediately below the 'sling complex'. In all cases the superficial fibres are in direct contiguity with the deep fibres and not really separable therefrom except posteriorly where, in most instances, a gap can be dissected out between the 'sling complex' fibres above, passing into the middle strata of the ano-coccygeal raphe and the rest of the external sphincter fibres passing into the lower strata of the raphe. This is known as the post levator space or the space of Courtney or Brick (1949) quoted by Pontius (1958) who describe it in somewhat ambiguous terms. Through it the ischio-rectal fossae communicate with each other. It contains a constant leash of vessels and nerves from each side and is thought to be the route followed by horse-shoe shaped ischio-rectal abscesses. It is illustrated in Plate 4.7. It is also conveniently situated to act as a posterior pulley in muscle transplant sling operations of various types. Occasionally an additional space above the sling complex and below the levator is demonstrable. It is shown in Part IV, Section 2.

Terminals of the conjoined longitudinal coat are frequently seen to emerge between the fibres of the superficial layer and pass into the ischio-rectal fossa although, as Fowler (1963) has noted, the ischio-rectal septum is not an anatomical entity.

Prerectal and other fibres from both layers of the levator may pass

/down ....

down in fan-like sprays lateral to the superficial and subcutaneous fibres to which they became attached. Such wandering musculature tends to confuse the issue in the perineum.

5. Deep External Sphincter

These fibres blend, as described, with the fibres of pubo-recto-analis from which they are distinguishable only by tracking them to an anterior attachment to the perineal body, whence a few appear to continue into the deep transverse perineal musculature. Photo 2.55, which is above Photo 2.54 and of the same specimen, shows intermingling of levator and external anal sphincter fibres laterally and posteriorly. On the right the band of P.R.A. is cut obliquely as it passes downwards, backwards and medially to commingle with the deep external sphincter. Anteriorly recto-urethralis fibres from the longitudinal coat are clearly seen. To show another view of the relationship of the external sphincter to the pubo-recto-analis Photos 2.56 and 2.57 form a sequence. They are of a sagittally sectioned adult male pelvis.

Photo 2.56 illustrates annular external sphincteric fibres forming a band anteriorly. Note the well marked ano-rectal angle and the stratified raphe behind it and the anal canal. In Photo 2.57 the medial aspect of the right side of the external sphincter has been exposed by dividing the anal canal, including its conjoined coat, and flapping the proximal and distal portions out of the way. 'X' covers the cut end of the annular fibres seen in Photo 2.57. Following this dark band to the right it becomes obscured by pubo-recto-analis fibres joining the 'sling complex'. Above, cranial fibres of levator joining the raphe are visible and at the top of the picture a few ilio-coccygeal fibres, passing lateral to pubo-coccygeal, appear.

Many of these deep fibres are purely annular and in two infants, out of four examined at post-mortem, a well defined band could be clearly delineated as illustrated in Photo 2.58.

Photo 2.58 shows levator fibres above and external sphincter fibres below. Ilio-coccygeal fibres are seen to the right. The fat laden

/fascia ....

fascia largely obscures the muscle fibres which are very thin. The annular band is indicated in the lower half of the field.

Photo 2.59 which is of the parasagittally sectioned 14 weeks old female foetus shows the form of the external sphincter and its relationship to the levator ani muscle. The space of Courtney is suggested posteriorly.

Occasionally fibres from the ischio-pubic ramus accompany the third part of the pubo-recto-analis and reach the coccyx as mentioned earlier. The sling complex is bound to the coccyx, as previously stated, by fibres which join the intermediate/middle strata of the ano-coccygeal raphe.

It seems possible that Courtney's 'figure-of-8' concept, as quoted by Parks (1958) , might be applicable to some of the deep external sphincter annular fibres which pass forward to the perineal body. His idea that these are pubo-recto-analis fibres, which have encircled the anal canal and then inserted anteriorly at a slightly lower level, is an attractive one and the embryological origin of these fibres would then be in common with the levator ani, and not from the anal tubercles like the rest of the external sphincter, as described by Tench (1936).

I cannot, however, agree with Parks (1958)that the whole of the pubo-recto-analis belongs to the cloacal sphincteric musculature for reasons set out in Section 2.

The anal tubercle is shown in Photos 2.60 and 2.61 which is of an eight week old embryo.

Photo 2.60 is a parasagittal view of an eight week old embryo which shows the bulbus analis. One gets the impression that the cloacal membrane has but recently disintegrated. The anal tubercle is well defined. The notochord is visible in many of the vertebrae. The genital tubercle is also seen clearly anteriorly. Photo 2.61 shows a close up view of the anal tubercle and newly formed anal canal.

6. Descriptions and Illustrations of the External Anal Sphincter

Many painstaking dissections have been illustrated by highly

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ordered diagrams and drawings and most beautifully show the general arrangement of the external sphincter. Netter (1962) has depicted variations found by Gorsch in technicolour, Hiller (1959) and Fowler (1963) have illustrated these variations in black and white, Grant (1962) and most current texts in monotone - A curious error in Fig. 40 (Fowler (1963)), is the direction of bulbo-spongiosus fibres which are shown in reverse. It is extremely difficult to indicate the whorling and interlacing and overlapping by levator ani fibres which careful dissection reveals and, indeed, these attachments are confusing, but they must always be remembered so that a particulate arrangement of external sphincter in separate blocks, pubo-recto-analis as another entity and the levator ani as a third is not the mental picture of the situation which the surgeon carries in his mind's eye.

Histology demonstrating this interlacing is in Part 7.

Addendum

Most authors seem agreed that external anal sphincteric musculature, though frequently of somewhat meagre proportions, is always present in victims of ano-rectal anomalies. On the other hand when the whole hind-gut and the mid-gut below the ileo-caecal region is missing, as occurs in cases of vesico-intestinal fissure (Wilson, (1967)), no trace of sphincteric musculature is found either on gross or histological search. Photo 2.62 illustrates this point. It shows skin and subcutaneous tissue at the expected site of the external sphincter.

7. Blood Supply

This is most carefully documented and illustrated by most authorities. Hiller's (1931) observation that the entry of the main inferior rectal branches at 5 and 7 o'clock in relation to the circumference of the sphincter accounts for the common location of fistulous openings in these positions is of some interest. The tracks of these in his opinion follow perivascular spaces.

8. Gross Nerve Supply of External Anal Sphincter and Lower Aspect of P.R.A.

I can only confirm the gross anatomy of the nerves - branches of the pudendal and perineal branch of the fourth sacral, which reach the skin and external anal sphincter enclosed as neuro-vascular bundles in fascial sheathes which traverse the ischio-rectal fossae. They are beautifully illustrated after dissection by Pernkopf (1963), Netter (1962), Grant (1962) and many others. A fairly comprehensive table of the distribution of the pudendal nerve is given by Bors (1952).

Photo 2.63 shows the pudendal nerve and its branches lying lateral to the levator ani muscle and above the external sphincter in an enucleation specimen. From above down the dorsal nerve of penis, internal pudendal artery, perineal nerve and inferior haemorrhoidal nerve can be discerned.

The main branches come from the inferior rectal (haemorrhoidal) nerve and perineal branches of the pudendal nerve. The last named arise just posterior to the deep perineal pouch and have been termed 'sphincteric' by Gorsch (1962). Their distribution can be seen in Plate 2.69 which illustrates the first part of the pubo-recto-analis which receives these sphincteric twigs in addition to innervation from above. The general distribution of these nerves in a newborn infant is indicated in Figs. 2.64 and 2.65. Fig. 2.64 shows a drawing of nerves seen in a 28 week old male foetus, which illustrates links between them, as well as with the perineal branch of the posterior cutaneous nerve of thigh. In general branches seem to enter the muscle in a downward and medial direction almost at right angles to the muscle bundles but sometimes they enter more obliquely as shown in Fig. 2.65. There seems no doubt that all four quadrants of the external sphincter receive adequate innervation.

PART 5.

DEEP PERINEAL POUCH (UROGENITAL DIAPHRAGM) INCLUDING RELATED UROGENITAL MUSCULATURE.

1. General Remarks

The superior fascia of the urogenital diaphragm is formed by a layer of fascia which is continuous laterally with tough fascia forming an extension from the pudendal canal, which in turn is formed by the fascia overlying obturator internus. Medially and anteriorly the inferior fascia of the levator blends with the upper layer and in the interval between the free medial edges of the levatores ani, with the superior fascia of that muscle which commingles with the retropubic venous plexus (prostatic in male) in the pre-urethral region and becomes firmly adherent to the urethra. This layer of fascia therefore is often well defined. Because of the network of veins in front and lateral to the urethra, and the perineal body behind, it is difficult to trace it convincingly to join the inferior fascia of the urogenital diaphragm (perineal membrane) anteriorly (in the transverse perineal ligament) and posteriorly, thus sealing off this little envelope of musculature.

The inferior fascia of the urogenital diaphragm is continuous with the anterior aspect of the forward extension from the pudendal canal and laterally near the conjoined ischio-pubic rami is very dense and fibrous but as it stretches medially it often becomes poorly defined, especially in the female, in whom the urethra and vagina occupy so much of the pouch that it may be difficult to identify, except in its lateral reaches. The antero-posterior width near the ischio-pubic ramus is frequently no more than 0.5 cm. in the female and may be only 0.25 cm. thick.

To the middle of its posterior border adheres that part of the perineal body which gives attachment to the posterior midline fibres of bulbo-spongiosus.

The number of large venous channels which form a plexus embedded in a fibro-muscular framework is the reason why this region presents difficulties to the dissector - these are illustrated in Photos 2.66, 2.67 and 2.68 low, medium and high power views, which show striped and smooth muscle and connective tissue interspersed between cavernous vessels in histological sections. These feed into the venae comites of the internal pudendal artery and these in turn are linked by one or more channels with the deep dorsal vein of penis - see Plate 4.7 or clitoris, by way of the plexus of veins in the retropubic space behind the symphysis and arcuate sub-pubic ligament. As blood from cavernous tissue passes mainly directly (deep dorsal vein) or indirectly into the prostatic plexus a reason for this collection of veins in the deep pouch is required. In Section IV I have formulated a tentative explanation for this plexus. These photos will receive further comment in that Section.

After a brief survey of the neuro-vascular supply to the urogenital diaphragm the striated and smooth muscles, which act on the urethra, will be considered.

2. Nerves and Vessels of the Urogenital Diaphragm

The nerves and vessels which pass into the deep pouch are shown in Plate 2.69 in which pubo-coccygeus has been detached from its origin and reflected medially.

They are:-

i) The perineal nerve which, having given off sphincteric branches and twigs to the deep pouch muscles and urethra pierces the perineal membrane, to supply superficial pouch muscles and the nerve to the bulb. The posterior scrotal/labial branches usually do not enter the pouch but they may, and they then pierce the perineal membrane. They are distributed to the lower part of the vagina in the female, as well as to labia and scrotum, depending on sex.

ii) The dorsal nerve of penis maintains an upper and lateral position, behind and above the perineal membrane, within the deep pouch. It then passes through a gap lateral to its artery giving a branch to the corpus cavernosum and its muscle before continuing on its penile course.

iii) The perineal artery - this gives off a transverse perineal artery

/which ....

which is often bigger than the continuing vessel,the artery of the penis, which gives off a sphincteric branch or branches and thencontinues through the pouch supplying a large artery to the bulb,shown in Plate 2.69. from which a small offshoot reaches the bulbo-urethral gland. Anteriorly it divides into the dorsal and deep arteries of penis, the dorsal joining the nerve from the medial side, and then,lying below it, as they transverse the suspensory ligament of the penis, before becoming medial again. The deep artery enters the corpus cavernosum penis which it traverses.

3. Striated Muscles.

a) Deep Transverse Perineal Muscles.

These vary greatly in development and are often very slender in the female. Their disposition in the saggittal plane is shown in Plate 4.7 and Photo 1.32. They are firmly attached to, and take partial origin from, both layers of the urogenital diaphragm, the deep external sphincter and the sheaths round the pudendal vessels as they traverse the deep pouch . One speciman showed layering of the muscle with the deeper layer transversely directed and the superficial one having a fan shape with the base directed upwards and laterally and the handle lying in relation to the sphincter urethrae muscle. When the perineal membrane is ill-defined it may be difficult to separate deep and superficial transverse perineal muscles from each other. In one speciman reffered to in section 2 I was unable to define a perineal membrane at all. Many deep transverse perineal fibres reach the perineal body and others blend with each other and with the sphincter urethrae and in the female with the vaginal wall.

b) THE EXTENT OF SPHINCTER URETHRAE.

Discussion No current textbooks of Anatomy mention striated muscle as an entity which extends above the urogenital diaphragm in relation to the urethra ,nor do they describe the blending of striped sphincteric fibres with smooth muscle ones, which is a rather arresting feature of their relationship. Yet evidence has accumulated

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through the years which indicates that striated muscle extends up to, or almost up to, the bladder neck in both sexes. I propose briefly to outline this evidence and show pictures of one female foetus and one newborn infant which illustrate these points.

Wood-Jones (1902) examined thick pelvic sections histologically in two male foetuses and three female ones and drew attention to a cylindrical layer of striated fibres extending in the male over the lower prostatic and membranous portions of the urethra.

Uhlenhuth (1953) gives historical notes on the anatomical concepts which have held sway from the time of Versari (1897 - 98), who reviews the earliest literature, up to Macalpine's 1932 contribution. He adds his own views and conclusions. His parasagittal views on the male pelvis L 1-4 are the least impressive of all his illustrations. For example the sphincter urethrae, as depicted in L4, is almost as large as the external anal sphincter.

Stephens (1963) performed microscopic sections of three male and four female children to define the extent of the external sphincter and the internal sphincter in them - he confirmed the findings of Wood-Jones and found that in males a little more than three-quarters of the posterior urethra and the whole urethra in females was related to striated muscle. Their diagrams are a little difficult to interpret and give the impression that striated muscle extends higher posteriorly than anteriorly. It is clear that many variations of its exact extent must exist in different subjects.

Mitchell (1968) in a review of urethral injuries and their complications claimed that the urogenital diaphragm is substantially larger during life than it is in dissecting room specimens. A reason for this is that the upward extension of striated muscle described above is competent and therefore a zone of narrowing of up to 3 cm., which is more than twice the expected length of the membranous urethra, may be seen.

Stephens (1963) shows this phenomenon in children with great clarity. Mitchell (1968) however, had some curious anatomical

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misconceptions. One was that the verumontanum (seminal colliculus) began near the lower end of the prostatic urethra and extended down into the membranous part; by this manoeuvre he gained extra length for his membranous urethra.

Gross evidence of striated muscle extending above the urogenital diaphragm is not convincing and this I believe is because the striated muscle intertwines with the smooth in the wall of the membranous part as shown very clearly in Photo 2.70 and then passes up as shown in Photo 2.71. These fibres were in the postero-lateral urethral wall of the female neonate (shown in Photo 1.33) just below the bladder neck. Striated fibres both transversely and longitudinally orientated as an intrinsic part of the urethral wall can be distinguished. These fibres must represent the ascending part of Kennedy's (1946) complicated 'muscle of mincturition.'

It would be very satisfactory to see longitudinal striated muscles gaining attachment to the trigone, as these would be in a mechanical position to alter the posterior urethro-vesical angle, but so far we have not seen such attachments. We intend to keep looking for them.

c. Sphincter Urethrae and Associated Striated Muscles

Female - Upper

Sphincter urethrae extends above the urogenital diaphragm and it would appear that the longitudinally disposed fibres noted above become arrayed in a mainly transversely directed horse-shoe formation anterior and lateral to the upper reaches of the urethra as shown in Photo 2.72. Photo 2.73 is a close up of the area marked to show striations. Interlacing with smooth muscle is still a feature. This specimen is a transversely sectioned female foetus aged five months.

Middle

Here a striated circular collar joins a raphe which might be termed the urethral body between the urethra and vagina. Photo 2.74 and Photo 2.75 which are low and high power views show this arrangement.

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The lower two thirds of the urethra as shown by many workers, including Krantz (1951), is firmly embedded in the anterior wall of the vagina and below the urethral body striated fibres in Photo 2.76 can be seen to pass transversely in front and on each side of the urethra to join the vaginal wall in company with some smooth muscle fibres.

Photo 2.77 is a high power view which shows pubo-coccygeal fibres to the right and striated muscle of the urogenital diaphragm related to the anterior and lateral aspects of the urethra. The party wall between the vagina and urethra is clearly visible. Within the urogenital diaphragm deep transverse perineal muscles blending with the sphincter urethrae are illustrated in Photos 2.76 and 2.77. This view (Photo 2.77) attests to the separation of levator ani from deep pouch muscles by a well developed fascial layer. A few fibres also join the vaginal wall.

Krantz (1951) has suggested that decussating fibres of bulbo-spongiosus and ischio-cavernosus contribute to this striated sphincter and the appearance of the raphe in Photo 2.77 a does lend some support to this contention although much further evidence on this point is needed. The difficulty in interpretation of urethral musculature in pelvic sections lies in the 16° angle noted earlier which distorts relationships considerably as does the plane of the urogenital diaphragm. The function of bulbo-spongiosus as a subsidiary urinary sphincter is unassailable. This function is achieved by virtue of its superior and lateral position which allows of urethral compression.

Lower

Near the external urinary meatus the urethra in Photo 2.78 is seen as a tube formed largely of connective tissue with minimal smooth and no striated muscle. In this region the venous plexus of the 'corpus spongiosum urethrae' is especially well seen. The finding of no striated muscle is in accord with the findings of Ricci (1950); contrary to his findings smooth muscle and not only fibrous tissue is present in this region. Bulbo-

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spongious can be seen to encase the vagina in Photo 2.79 which also shows the relationship of this muscle to Bartholin's greater vestibular gland.

The crura and ischio-cavernosus are relatively remote at this site as Photo 2.80 indicates.

Striated musculature, which can act on the female urethra, and constitutes the external urethral sphincter include:

i) Sphincter urethrae with its upward extension to the bladder neck

ii) Some fibres of the deep transverse perineal muscles

iii) Some fibres of bulbo-spongiosus muscle.

d) Sphincter Urethrae and relates muscles

Male

Our male embryonic and foetal material was not suitable for determining the extent of striated muscle above the urogenital diaphragm but the existence of such musculature has, I believe, been conclusively proved by the evidence cited above.

Within the deep pouch sphincter urethrae fibres can be seen in Photo 2.81 to encircle the urethra which has been sectioned below the superior fascia of the urogenital diaphragm. The rectum and recto-urethralis are inferiorly placed and cut medial levatores frame the perineal body and urethra with its surrounding musculature.

The spongy urethra has fibres of bulbo-spongiosus impinging on its upper surface and these are responsible as Bell (1926) remarked for emptying the last few drops of semen and urine and was therefore called the 'ejaculator' muscle or alternatively the 'accelerator urinae'.

Stephen (1963) depicts micturating cysto-urethrograms which show the effects of voluntary contraction of the sphincter urethrae and the striking effects of voluntary contraction of bulbo-spongiosus on the urethral lumen.

Watson and Innes Williams (1952) describe remarkable hypertrophy of bulbo-spongiosus developed as a result of voluntary effort to maintain continence after nerve injury. This control however was

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not efficient at night.

The same striated elements then act directly on the male urethra as obtains in the female.

Conclusion

It may be that anatomists are reluctant to acknowledge striated muscle above the urogenital diaphragm because the neat compartments which subdivide the urethra would have to be breached,

In both sexes the role of the levator ani particularly, and the rest of the pelvic floor muscle in general, in moving the urethra and in altering the posterior urethro-vesical junction is considered in Section IV.

4. Smooth Muscle

All physiological studies have shown that the smooth muscle of the bladder and the urethra in the female consists of muscle fibres which are continuous with each other although it is agreed by most that functional differences between different parts of the muscle may exist. Our histological studies confirm the well-defined outer circular layer (which commingles with striated muscle in the regions mentioned) and the slender inner longitudinal coat, Many fine dissections, including those of Van den Bulke and Fine in Durban, have shown longitudinal fibres surrounding the orifices of the prostatic ducts thus preventing urine from entering the organ. At the bladder neck peripherally-sited anterior and posterior longitudinal bundles are occasionally described. Photo 2.82 illustrates such fibres anteriorly. Photo 2.83, which is a transverse section of the bladder in the trigonal area, shows the bladder lumen above and part of the wall of the cervix below. Between them is fibro-fascial tissue and smooth muscle (Utero-vaginal fascia). Dense smooth muscle of the detrusor can be seen to right and left. The longitudinal bundles are also formed of smooth muscle.

In the female the lowest portion of the urethra has only a diminished smooth muscle coat and is mainly a fibro-elastic tube

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with many venous sinuses in it as illustrated earlier.

5. Nerve Supply of the Smooth Muscle

Comprehensive reviews of the sympathetic and parasympathetic supply of the bladder and urethra were presented by Gruber (1933). He recorded in tabular form results of stimulation of pelvic nerves (nervi erigentes, pelvic splanchnics), hypogastric nerves and anterior primary rami of lumbar and sacral nerves obtained by different workers, in different animals and in man, from 1863 to 1930. Gaskell in 1887 was apparently the first to record contraction of the detrusor in man. Elliot T.R. (1906 - 7) first stated the presence of inhibitory nerves to the bladder and, with many thought provoking remarks, opened up a number of fields for further research. Bors (1952) and Kuru (1965) have also presented reviews of the subject.

6. Sphincteric action in the Proximal Urethra

The presence of a functional internal urethral sphincter is very strongly suggested by cysto-urethrographic studies and I was greatly impressed by cysto-urethrograms presented here by Mr. Marco Caine in 1968 showing reflux of urine from the proximal urethra back into the bladder at the end of micturition. This was clearly a taking up and closing off of this part of the urethra by the intrinsic detrusor and perhaps the trigonal smooth muscle as well. Similar closing off is generally believed to occur during ejaculation and may be under sympathetic control.

Normally after prostatectomy full continence is achieved and cysto-urethrograms show that sufficient smooth muscle and elastic tissue, and perhaps, a certain amount of striated muscle remains, to ensure that this reflux into the bladder occurs. Occasionally, however, it does not (Caine (1954)). Then despite adequate striated musculature, a cavity filled with urine can be seen to extend down to about the middle of the verumontanum and from time to time, with relaxation of the striated muscle, dribbling occurs.

Considering these facts in relation to the embryology of the urethra some points stressed by Louw (1965) are reiterated.

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The region of the prostatic urethra involved is that part which embryologically develops from the pars vesico-urethralis of the urogenital sinus. This develops as a result of downgrowth of the uro-rectal fold and can be differentiated from the distal part of the prostatic urethra and membranous urethra, which develop as a result of the inward surge of mesenchyme from the postero-lateral aspects of the embryo (primitive streak) Harrison (1959) which indents the sides of the cloacal cavity until they meet and fuse with each other in the midline, with the urorectal septum above, and the cloacal membrane below.

Thus that portion of the urethra, which is engulfed by cloacal musculature, develops from the pars pelvina of the urogenital sinus and when one considers this relationship it would be reasonable to expect striated muscle to extend above the urogenital diaphragm. The uro-genital septum containing the paramesonephric and mesonephric ducts was shown in Photos 2.42 and 2.43.

Functional differences between these two portions of the urethra could be envisaged on the basis of their embryology, but, as in the oesophagus, where striated and smooth muscles commingle at varying levels, so in the urethra clear cut exact boundaries need not be anticipated and variations are very likely to occur.

7. Functional considerations in relation to voiding and filling.

Woodburne (1961) amongst others, has remarked on the shortening and increase in width of the urethra (with funnelling of the bladder neck) which occurs during voiding due to detrusor contraction pulling the bladder neck open.

Also mentioned is the descent of the trigone below its fixed upper point with straightening out of the posterior urethro-vesical angle.

Van Duzen 1932 1945) observed a depression of the trigone, with a falling back of the posterior lip of the internal urinary meatus through the cystoscope, when patients were asked to strain and attempt to void. At the same time the lateral walls of the urethra seemed to retreat from the cystoscope as detrusor contraction proceeded from the bladder base to the fundus. They believed, as

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have many (e.g. Wesson (1920), Young (1926)) that contraction of the trigonal muscle initiates micturition. Muellner's idea that voluntary relaxation of the levator with a downward dip of the bladder base initiates the act, although theoretically attractive, has been attacked by many - the most cogent arguments stemming from the fact that detrusor contraction precedes pelvic floor relaxation - as shown by Rankin (1969) and Hinman quoted by Roberts J B M (1962). The descent of the pelvic floor, which immediately follows detrusor contraction, seems likely to be caused by the pelvico-abdomino-perineal reflex described by Kuru (1965). This reflex can be elicited after brainstem transection at the ponto-medullary junction in cats. Stimulation of the central stump of the cut sacral para-sympathetic nerves in these creatures evoked reciprocal responses in the abdomino-diaphragmatic muscles, which contract, whereas the levator-perineal group relax.

This clearly shows that afferents from the pelvic organs, or their immediate environs, can produce a synchronous response, which raises intra-abdominal pressure and paves the way for emptying of viscera.

At the end of micturition cine cysto-urethrographic studies show that the urethra becomes longer and narrower as the detrusor relaxes, elastic tissue become competent and the pelvic floor rises sharply in Porter's 'closing reflex' with restoration of the posterior urethro-vesical angle.

It is interesting to find that Denny Brown and Robertson in 1933 noted rapid and early closure of the external urethral sphincter at the end of micturition. During filling the urethra remains longer and narrowed and is occluded by muscle, elastic tissue and venous channels.

Woodburne in his 1969 Textbook reproduces the diagram from his 1961 article, which shows the pelvic floor ascending during micturition and descending during filling, the reverse of the radiologically proven situation.

The question of the relationship of longitudinal musculature in the ureters continuing into the trigone and, with Bell's trigonal muscle

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and the upper part of the prostatic urethra, forming a 'combined unit' although of great interest, is outside the scope of this thesis as is the question of sphincteric mechanisms in relation to the ureteric orifices as copiously expounded on by Hutch et al (1952, 1954, 1955, 1961) on several occasions.

8. Conclusions

Normally these elements act in harmony and the role played by striated and smooth muscle in the initiation of micturition would appear to vary from person to person as noted in Section IV.

The question of the relative importance of striated and smooth muscle in urinary continence will be considered briefly here and again in Section IV in relation to electromyographic findings. On balance the evidence for either component being able to function alone with reasonable efficiency appears irrefragible. Thus after bilateral pudendal nerve block the only disabilities are

i) inability to arrest the stream rapidly

ii) difficulty in counteracting rises in intra-abdominal pressure.

Also after radical prostatectomy the striated musculature can effectively maintain continence.

It is tempting to believe that the smooth muscle pubic ligaments with their related fascia act as fixed points which allow the emptying and filling of the upper urethra to take place and also possibly form the fixed point for approximation of the dome to the bladder neck as suggested by Uhlenhuth (1953).

PART 6.

COMPARATIVE ANATOMY

'When the naturalist has arranged animals according to their exterior appearance the anatomist deranges his ideas, by exhibiting, in the internal structure, transitions and gradations, which he did not contemplate and principles of arrangement, which he had not foreseen. But this does not controvert the general principle, that there is a chain of existence through the whole of nature. It only throws us back mortified that we do not perfectly comprehend the whole system; a conclusion which, however

/humbling ....

humbling, is exactly what man experiences in the pursuit of every other department of knowledge, whether the subject of his contemplation be the earth he inhabits, the creatures which partake it with him, or his own faculties and nature, and his condition in creation. And let us make the best of this truth, let us view it as promising to us an inexhaustible field for enquiry, and an ever new hope of discovery.'

Charles Bell (1826)

Paramore's (1910) description of the evolution of the pelvic floor in non-mammalian vertebrates and pronograde mammals has formed a scaffold for all subsequent investigations. I shall recapitulate some of his more arresting tenets with additions where relevant from my own dissections. As these have been limited to a few key forms the differences which are noted between my findings and those of others may all be due to variations, which in animals seem in this region to be almost as numerous as those which obtain in man.

1. Fishes

Paramore made the interesting observation that, in fish, the pressure of surrounding water prevents extrusion of excrement or ova and therefore a special cloacal sphincter is unnecessary - on the other hand for expulsion to occur contraction of the visceral musculature must be supplemented by contraction of body wall musculature and for this reason oblique fibres develop in the abdominal wall as their direction is such that their contraction will determine an increase of pressure towards the cloaca. A cartilaginous bar sited anterior to the cloaca is attached to the tail by caudo-pelvic strands of muscle.

2. Amphibians. Xenopus Laevis.

The pelvis of this creature, which is shown in Plate 2.84, has a cartilaginous epipubis of shield-like form and a bony hypoischium, which forms a support for the anterior tip of the cloaca and has the alternative name of 'os cloacae'. The iliac bone, which is rod-shaped, moves very freely on the sacrum or ninth vertebra, which articulates with a long, mid-line, cartilage-tipped stylet of bone known as the urostyle. This lies behind the cloacal opening.

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The urostyle and vertebral column are able to move by sliding on the long plane sacro-iliac joints which produces considerable lengthening and shortening of the whole animal used, J.Z. Young (1962) suggests, for driving into mud.

A definite cloacal sling shown in Plate 2.85 arising in front from the back of the pubis near the mid-line and from the hypoischium below this, see Plate 2.84, passes round the sides of the bladder, rectum, vasa and ureters in that order from anterior to posterior in the male and bladder, rectum, oviducts and ureters in the female, to unite in the mid-line and be attached by a fibrous raphe and one or two fine muscular strands to the mid-line of the urostyle behind, as shown in Plate 2.84. Plate 2.86 shows the strange arrangement of the pelvic viscera in this species.

One constant feature is the way in which a band of the compressor cloacae separates, as shown in Plate 2.85, passing lateral to the tenth spinal nerve and then fading out in the fascia of the posterior pelvic wall. Plate 2.85 also shows a median muscle which moves the epipubis upwards and backwards - this reduces the volume of the abdominal cavity and drives air from the air sacs into the head rendering this part more buoyant - the function propounded for the ypsiloid. According to Hoffman (1930) quoted by van Dijk (1955) the ypsiloid cartilage must be considered as homologous to the epipubis of Xenopus, but other workers quoted by van Dijk are not as certain of the homology.

The pelvic musculature of the amphibian, which is essentially aquatic, shows that cloacal musculature has now been added to encircle the cloacal apparatus as the creature is normally in shallow water and in times of drought may become separated from its natural habitat.

3. Reptiles

According to Paramore (1910) caudopelvic muscles are conspicuously present and assume a more complicated form. Forerunners of pubo-ilio and ischo-caudalis appear to be present in the form of antero-posterior and lateral bands.

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4. Birds

Seagull - Species Thalasseus Bergii Bergii

This bird has a most elegant arrangement of pelvic floor musculature in relation to its cloacal apparatus. Surrounding the cloaca is a perfectly symmetrical, sphincteric collar of circularly arranged muscle fibres which rostrally is tethered to musculo-aponeurotic fibres of the abdominal wall. Passing down on each side of the sphincter, and firmly bound to it by fascial connections, are the pubi-coccygeus internus muscles. These pass from the inner and upper aspects of the spine-like projection of bone, which represent the pubic element of the synsacrum in birds, to the inferior and lateral aspects of the synsacrum above the pygostyle. They are shown in Plate 2.87 and Plate 2.88 and Photos 2.89 and 2.90. Pubi-coccygeus externus passes from the outer aspect of the pubis and diverges from internus to be attached to the lateral aspects of the synsacrum as shown in the above illustrations. Posterior to pubi-coccygeus internus, ilio-coccygeus may be discerned, with its fine tendon reaching the synsacrum above the insertion of pubo-coccygeus as shown in Photo 2.89 and Plate 2.87. The nerve supply is faintly indicated in Photo 2.89 as well. Outside pubi-coccygeus externus a transversely directed band of muscle, which arises from a postero-laterally sited spine on the ischium, (for which I was unable to find a name in the literature available to me) termed transverso-analis reaches and blends with the lateral aspects of the cloacal sphincter as pictured in Plate 2.88. Inferiorly and posteriorly fine bands of muscle can be seen to pass along the medial edges of pubo-coccygeus internus from the upper limit of the cloacal sphincter to be inserted into the synsacrum. These may be termed m. suspensor ani and are shown in Plate 2.88 and Photos 2.90 and 2.91 which shows a close-up view of part of the right suspensor ani muscle.

In the interval between the free edges of pubi-coccygeus internus the glistening criss-cross aponeurosis of the powerful muscles, which move the pygostyle and tail feathers, can be seen. This is indicated in Plate 2.87 and well shown in Photos 2.90 and 2.91.

/ Photo ....

Photo 2.92 is a posterior view showing the dorsal and lateral muscles of the synsacrum and tail. Two well-developed oil glands (uropygial) are present, these help this sea-bird keep its feathers dry, furnish them with ergosterol, which is converted to Vitamin D by sunlight, and impart a characteristic odour to the creature.

Photo 2.93 shows the very large kidneys in this sea-bird, part of one testicle, the ducts which pass down to the cloaca from them and the bowel with its paired caecal appendages. The key to these features is Plate 2.87 which shows the testes to be unequal in size.

The names of the muscles were obtained from P.P. Grassé's Traité de Zoologie (1950) whose diagram of the cock (gallus gallus) on p. 128 shows a slightly different arrangement from that found in the sea-gull. No ilio-coccygeus is pictured and I have not found descriptions of any of these muscle attachments.

Conclusions

Despite wide separation of the pubic bones in birds adaptations of the musculature have occurred which close off the pelvic floor and give additional protection and support to the viscera.

Are the transverso-analis muscles perhaps homologous with the superficial transverse perineal muscles which arise from the ischium and merge with the external anal sphincter in man?

Pubi-coccygeus internus and ilio-coccygeus seem likely precursors of the levator ani - is pubi-coccygeus externus perhaps the homologue of ischio-caudalis in the baboon and (ischio) coccygeus in man?

5. Mammals

In most terrestrial mammals the caudo-pelvic musculature can be divided into pubo, ilio and ischio-caudalis (coccygeus) which are attached to the inner aspects of the hip bone anteriorly and laterally and to the lower regions of the vertebral column posteriorly. In addition a cloacal sphincter develops during embryonic life which becomes subdivided by the perineal body (eighth week in man) into

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a posterior sphincter surrounding the terminal bowel and anterior musculature surrounding the urethra and erectile tissue in both sexes.

a) Rodents - Mus Norvegicus Albinus.

Seven rats were dissected, four female and three male rats.

In the rat pubo and ilio-caudalis are well defined slender muscles. The former arises from the back of the body of the pubis and superior ramus, the latter from the lower half of the medial surface of the ilium extending up to the pelvic brim. At their insertion ilio-caudalis joins pubo-caudalis as they pass to a common insertion into tendons of the anterior and lateral surface of the base of the tail. Their disposition is shown in Photo 2.94. The medial edge of the left pubo-caudalis is in the centre of the picture.

For some reason Eunice Green (1955) refers to pubo-caudalis as abductor caudae externus and ilio-caudalis as abductor caudae internus as nothing in their relationship bears out this description. In the 1955 edition of the Anatomy of the Rat Fig. 91 and 93 show levatores ani muscles, which resemble nothing seen in the rats I have dissected, and although listed in the index the levatores ani are not described in the text. No picture of her abductor caudalis muscles are included but I imagine that the new edition of this work, which I have tried in vain to secure, will have remedied these defects. Ischio-caudalis passes to its insertion into the lateral aspect of the base of the tail. It is covered by the bulky long caudal flexors and ilio-caudalis.

In three specimens a few muscle fibres passing from the rectum to the posterior pelvic wall which might be termed m. retractor recti et vaginae were seen and Photo 2.95 shows this feature. The rectum is viewed from the left side.

Striking was the straight course of the bladder into the urethra in both sexes and the separation of the urethra from the vagina in the female, so that below, an anterior opening in front of the vaginal opening was distinguishable. The

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bicornuate uterus has very long tubes which, with the ovaries, are sited well up in the abdominal cavity.

The ano-rectum pursues an entirely straight tubular course and terminally a slender external anal sphincter surrounds it. In some forms apparently it is more robust.

b) Ungulates

In this group pubo and ilio-caudalis are entirely absent and the ischio-caudalis is the only muscle of the group but it does not form as extensive a sheet as it does in rodents. An ischio-anal muscle is present which is almost as well developed as ischio-coccygeus. It is inserted into the terminal part of the rectum in close association with the well developed external anal sphincter. According to Peter Thompson (1899) quoted by Paramore (1910) this represents a greatly developed transverse perineal muscle and has evolved from the primitive cloacal sphincter.

Procavia Capensis Capensis - 2 specimens, 1 male and 1 female are described.

The pouch of Douglas in these creatures is very deep extending almost to the perineal body, and, anterior to the anterior leaf, there is a very striking sheet of fascia, which greatly resembles Denonvillier's fascia except for its peritoneal relationships. In front of this are fleshy vasa, only slightly dilated in their ampullary portion, and the seminal vesicles, which extend to the upper limit of the bladder in this creature and have a surface resembling a mulberry. They are united to each other by a genital fascial layer which runs between them and to the bladder as well.

The attachment of the ureters to the fundus of the bladder near the mid-line is somewhat reminiscent of the attachment of the tubes to the uterus and the well-developed prostatic plexus and absence of urethro-vesical angle are all noteworthy.

The pelvic floor muscles are as described by Paramore (1910) coccygeus having its broad triangular form, arising from the ischial spine and spreading to a wide insertion on each side of

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sacro-coccygeus anterior. In one dassie the pubo-coccygeus is represented by narrow slender bands arising from the back of the body of the pubis on each side and being inserted as fleshy slips into the ventral aspect of the coccyx. They lie obliquely inclined, as shown in Photo 2.96, on each side of the anal canal as they pass back to their insertion. In the other dassie the slender strap-like muscles arises from a shiny aponeurotic origin and then pass obliquely embracing the prostate and ano-rectum on each side to tendinous insertions on the anterior aspect of the lower part of the coccyx. This contrasts with the first specimen, whose coccygeal insertion is fleshy and reaches the anterior aspect of the tip of the coccyx. In Photo 2.97 the right pubo-coccygeus can be traced from the pubic bone (to the right of my finger) to the front of the tip of the coccyx. A very slender nerve filament was traced on each side over ischio-coccygeus, medial to the undescended testis on each side, and into the middle of the lateral edge of the muscle. No nerve filaments were seen entering the muscle from its lower aspect.

The external sphincter forms a delicate band encircling the anus.

Discussion

These creatures although bearing a singular resemblance to rodents have:

i) A long gestation period of ± seven months.

ii) Seldom have more than two and often only one offspring at a time.

They are considered to have survived in a modified form from the Ungulates of antiquity. It is of interest that the earliest forms are not by any means easily differentiated from the primitive carnivorous mammals of that date - the Creodonta. In both specimens no trace of the rest of pubo or ilio-coccygeus was present, which is certainly a strong point in favour of an ungulate ancestry. Two impressive features I think are that the slender external sphincter is apparently compensated for in this species by:

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a) The way in which gluteus maximus is attached to the lateral margins of the coccyx as well as to the sacrum, ilium and sacrotuberous ligament, so that its medial margin abuts on the external anal sphincter, which consists mainly of circularly disposed fibres, a few millimetres in depth, a few of which gain attachment to the tip of the coccyx. This muscle is thus ideally situated for exerting side to side compression on the external anal sphincter in this pronograde creature.

b) The way that the coccyx overlaps the dorsal margin of the anus so that the pubo-coccygeal fibres are perfectly placed to hinge this mobile cartilaginous portion forwards and help close off the straight tubular ano-rectum.

Paramore (1910) noted that the pelvic floor muscles of ungulates have regressed because, becoming herbivorous and hoofed, they avoided movements which raise intra-abdominal pressure like crouching, breath-holding during attack and loud vocalisation. The anal opening, surrounded by its powerful sphincter, was placed almost at the summit of a very obliquely inclined pelvis and defaecation can occur during locomotion without any straining.

In Carnivores however, who must hold their breath to fix muscles during attack and defence, who use their digits for clawing and grasping and who sit, crouch and make an assortment of loud noises, pubo and ilio-coccygeus developed to counteract these rises in intra-abdominal pressure and strengthen the pelvic floor.

c) Aquatic Mammals

Sphincteric muscles are well developed in marine mammals and ischio-anal muscles like those of ungulates are found. These, Paramore (1910) suggests, are correlated with the terrestrial type of respiration and circulation and the presence of a thoracic diaphragm. Intra-abdominal pressure similar to that in land mammals is present and probably rises considerably

/during .....

during spouting which is a noisy operation.

d) Cercopithecidae Baboon - Papio Ursinus

I have had access to one male specimen dissected by Professor Trevor Jones in the Department, have dissected further another male specimen of his and have completely dissected one young male and one young female and have partly dissected a male foetus. Not all the material shows every feature clearly due to difficulties with preservation.

The form of the baboon pelvis is shown in Photos 2.98 and 2.99.

Pubo-caudalis

This arises from the anterior and medial portion of the pubic bone; from the upper margin of the obturator foramen to the midline. Because the bodies and inferior pubic rami join in a deep V the anterior origins are very close to each other and are attached along the whole length of each side of the symphysis. A few fibres are inserted into the perineal body and the rest sweep downwards, slightly medially and backwards, to be inserted on upper caudal vertebrae on their ventral and lateral aspects. A few fibres, in one specimen, pass from the under-surface of the anterior and medial portion caudal to the m. retractor recti, which it closely embraces, to join the upper-most part of the external sphincter fibres behind the anal canal.

As shown in Plate 2.100 the M. Retractor Recti (et Vaginae) is a well developed muscle with a most interesting form. It embraces the ano-rectum above and below the ano-rectal junction as shown in Photo 2.101 and Plate 2.100 - being 2 cm. in depth posteriorly and less than 0.5 cm. in depth anteriorly. Each half of this bivalved muscle is attached to the perineal body in front and receives smooth muscle from the bowel wall medially and striated muscle from the adjacent levator ani laterally and anteriorly. Posteriorly it is inserted onto the sacrum by two prongs.

Photo 2.101 shows the rectum cut across and the two limbs of the m. retractor recti embracing the bowel and passing to the left to gain attachment to the coccyx. On each side of the rectum

/levator ....

levator fibres can be made out passing towards the tail. From above it is seen to lie medial to the levatores ani and in relation to the hinge of the valve smooth muscle arising from the back of the bowel passes as a pale plump cord backwards and downwards to become attached to the front of caudal chevron bones. This is the caudo-rectalis muscle. **(recto- caudalis)**
These two muscles are clearly homologous with recto-coccygeus in man.

When viewed from below (see Plate 2.100 and Photo 2.102) it is seen that the two halves of the m. retractor recti overlap the levatores ani slightly as they pass forward to the perineal body. Below they merge with the external anal sphincter. The complex horseshoe band of levator is seen fully in the plate and less distinctly in the Photo. Note the disposition of the recto-caudalis muscle in Plate 2.100 and Photo 2.103.

Ilio-caudalis

This muscle arises from the pelvic brim and extends anteriorly, in front of and below the obturator foramen, superficial to pubo-caudalis. Posteriorly it almost reaches the sacro-iliac joint. It is a powerful, fleshy muscle at least 0.5 cm. in its thickest middle portion and, as it passes medially, usually all but its posterior margin disappears caudal to the antero-posteriorly running pubo-caudalis fibres and is then inserted in common with pubo-caudalis into the upper three caudal vertebrae. In one a tendon was seen to pass down from it and join a leash of tendons on the flexor aspect of the tail. Photo 2.104 shows the obturator nerve and vessels passing between the pubo- and ilio-caudalis. Pubo-caudalis with its extensive anterior origin is to the left of the picture, where the symphysis is located, and ilio-caudalis can be seen to extend to the pelvic brim above the obturator nerve.

Ischio-caudalis

Unlike that of the Rhesus Macaque, whose pelvic musculature otherwise closely resembles that of the baboon, this is completely hidden from the pelvic surface by pubo- and ilio-caudalis. It is attached to the poorly developed ischial spine and adjacent ischium

/and ....

and has a quadrangular form passing to be attached to the sides of the lower sacrum and upper caudal vertebrae. It is illustrated in Photo 2.103 and Plate 2.100.

Photo 2.105 shows a parasaggital section of a female baboon pelvis cut to the right of the mid-line. The disposition of the pelvic organs is shown and the reinforcing muscle funnel formed by pubo and ilio-caudalis and the m. retractor recti above. The external anal sphincter below is only suggested. Ischio-coccygeus bolsters the levator muscles at the sides. Note the bulk of obturator internus muscle below pubo-coccygeus.

Long and short caudal flexors appear to follow the pattern described by Brazier Howell and Strauss (1961) in the Rhesus Macaque.

External Sphincter

The external anal sphincter consists mainly of annular fibres arranged round the lower anal canal. It is not strikingly developed.

Discussion

Judging by the development of the muscles in this species it would seem that pubo-caudalis is purely concerned with supporting and fitting round the pelvic viscera in a sphincteric fashion, that ilio-caudalis helps in this function and that both, by flexing the base of the tail, may help with closure of the anal orifice. Because ilio-caudalis is so well developed it doubtless helps in abducting movements of the tail as well.

Ischio-caudalis may reinforce the action of the deeper muscles and may have some slight abducting action at the base of the tail. The funnel shaped form of the pelvis is well shown in Photo 2.105.

The striking development of the pubo, ilio and ischio- caudalis may be accounted for by the very meagre fascial layers found in this species. The superior fascia of the levator is thin and filmy and the septal layers, though present, are not striking therefore the muscle bulk must increase to counteract rises in intra-abdominal pressure and to support viscera during upright activities.

The urethral sphincter surrounds the urethra just caudal to the

/prostate ....

prostate. Its fibres are attached to the mid-point of the perineum and to the pubo-prostatic ligament.

In the female, cloacal sphincteric musculature is very similar to that found in the Rhesus Macaque.

The perineal muscles resemble those described by Howell and Strauss in the Rhesus Macaque except that a powerful fibro-tendinous layer passes between the ischial tuberosities, holding the ischio-cavernosus and bulbo-spongiosus in position, and making their dissection difficult.

Nerve Supply

The pudendal nerve is distributed to the inferior aspect of the external anal sphincter, levator ani and perineal muscles as in man. The position of the nerve and some of its branches is shown in Plate 2.100.

The nerve to the levator ani has the distribution shown in Photo 2.104 and as in the chimpanzee and man the nerve passes from the same leash of fibres as the nervi erigentes and forms a plexiform arrangement as illustrated.

In this specimen the nervi erigentes and nerve to the levator ani arise by twigs from S2 and S3 which form a loop and are then distributed via an upper branch, which passes through the pelvic plexus (formed by hypogastric and nervi erigentes uniting) to reach the rectum, lower ureter, bladder, seminal vesicle, vas and prostate and also gives a well defined branch to pubo-caudalis, and a lower branch which gives direct offsets to the rectum, muscular twigs to ilio-caudalis and m. retractor recti and then reinforce the muscular supply of pubo-caudalis anteriorly. Here it runs in close proximity to the upper branch and gives off visceral twigs as well. Cavernous fibres leave the anterior end of the plexus.

The loop, upper and lower branches and some of the muscular and visceral offsets passing from left to right to the right ilio- and pubo-caudalis and the right pelvic plexus are visible in Photo 2.106.

/e) ....

e) Chimpanzee - Pan

In speaking of the evolution of the pelvic floor in Primates Elftman (1932) remarks that the 'salient feature is the loss of muscular development with the compensatory development of tendon and fascia which can withstand long continued stresses without expenditure of energy, but cannot provide motive power'. Elftman does not develop this theme to any extent. The significance of this statement did not strike me until I had fully appreciated the essential role of the pelvic fascia in weight bearing as elaborated on in Section I.

The pelvic musculature differs from that in man because of the bony structure of the pelvis and also because the upright position is not the habitual posture of these creatures. Walking is assisted in them by the upper limbs, the knuckles of which make contact with the ground.

Levatores Ani

Our specimen must have belonged to a different species from the one illustrated by Elftman (1932) as pubo-coccygeus much more closely resembles that shown in his drawing of the gorilla pelvis having fine tendinous portions anteriorly - shown in Plate 2.107 and Photo 2.108 which extend well up the back of the body of the very long pubic bone and then along the superior ramus to the obturator foramen as in man ('high' origin). The fleshy part ends anteriorly in two rounded peaks. Sonntag's (1923) description of these muscles, including this part of it, is cursory and as he makes no mention of a part of psoas major which arises from the ala of the sacrum and passes anterior to the sacro-iliac joint which it obscures, a most unusual feature, I am not convinced that he dissected the levator ani muscle fully as this entails removal of the very dense superior fascia and negotiation of prominent septal layers as well.

A few pubo-coccygeal fibres in our specimen join the ano-rectal walls and a few cross the midline as shown in Plate 2.107, a few join the external sphincter but the vast majority proceed directly into the very long and well marked ano-coccygeal raphe and a few are attached to the coccyx behind it. Elftman (1932) observed the failure in apes of the coccyx to reach the level of the anus (or more accurately the anal canal) as a condition

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which contrasts markedly with that in humans and certainly the length of the ano-coccygeal raphe (± 6 cm.) is impressive - see Plates 2.109 and 2.107.

As mentioned most fibres posterior to the rectum join the raphe but the caudal 1.1 cm. of the muscle does show some thickening and a very few fibres crossing the midline were definable and these might foreshadow the pubo-recto-analis in man. The most posterior fibres are attached to the sides and front of the coccyx and become markedly tendinous as they approach the midline.

Posterior to the obturator foramen two other muscle elements are distinguishable extending back along the pelvic brim as far as the tendon of psoas major and the fibres which pass to it across the sacro-iliac joint referred to earlier.

Ilio-coccygeus has some muscular and some tendinous elements and an aponeurotic sheet. Posteriorly it passes caudal to pubo-coccygeus medially and behind this is attached to the side of the coccyx as far back as the inferior lateral angle of the sacrum but this portion lies in a caudal plane to the rest of the muscle. The posterior coccygeus muscle which has a strange form for coccygeus has a fan-shape illustrated best in Photo 2.110 and medially some fibres attach to the side of the lower sacrum the rest, becoming thinly aponeurotic, can be traced anterior to the pyriformis to blend with the periosteum of the anterior sacral surface in relation to the sacral sympathetic chain. A sacro-spinous ligament as shown on the inside of the pelvis in Elftman's illustration is not present in our specimen. The sacro-tuberous ligament which is a recurved thickened portion of the gluteal fascia resembles the inguinal ligament in that its floor gives rise to some of the fibres of gluteus maximus muscle - as illustrated in Photo 2.111 and 2.112.

In Photo 2.111 fibres of the left gluteus maximus are seen passing from a vertical line of fascia positioned at about the junction of the left two thirds with the right third of the plate. This is the site at which the fascia covering the muscle passed under it to cover

/gluteus ....

gluteus medius and in doing so formed a curved gutter for attachment of gluteus maximus fibres.
Photo 2.112 shows these detached muscle fibres and part of the undersurface of the muscle flapped towards us and part of the curved fascial bed of origin is revealed.

Nerve Supply

The innervation is shown in Plate 2.107 the nerves for all the pelvic diaphragm come from S3 in common with the lowest of the nervi erigentes. From S3 branches which supply coccygeus and ilio-coccygeus can be seen and the continuing stem runs in Waldeyer's fascia giving off nervi-erigentes to the pelvic plexus and then continues to the anterior part of pubo-coccygeus.

The pelvic plexus is very well developed and receives para-sympathetic fibres from S1, 2 and 3. See Photo 1.31. The fibres from S2 come off a common stem with the pudendal nerve which I imagine is why Wozniak et al (1967) describe contributions to the plexus from the pudendal nerve.
Most interesting are those autonomic twigs which pass medially from the main pubo-coccygeal nerve to the pelvic viscera. One pubo-coccygeal branch supplies fibres to the conjoined longitudinal coat and to the external anal sphincter as well.
If there is a myenteric plexus in the levator then here is the nerve which could so easily be involved in forming it.

External Anal Sphincter and Perineal Features.

This muscle is very well developed in the chimpanzee. In Photo 2.113 the part of the raphe receiving muscular fibres from the external sphincter fibres suggest the rounded form of this muscle. Above and to the left and below and to the right gleaming fibres of the levator ani are visible distorted because they have been detached from the pubis and ilium.

Elftman speaks of the sphincter ani externus as spreading out over (above) the bulbo-cavernosus (spongiosus) forming a floor for the urogenital region immediately below the fascia of the pubo-coccygeus, and thus replacing the deep transverse

/perineal ....

perineal muscle. This feature is well shown in Plate 2.108 and also noteworthy is the way in which the perineal body (central tendon of the perineum) is carried forward along the raphe for at least half the length of the undersurface of the corpus spongiosum as it receives antero-posterior fibres of the external anal sphincter.

Although the external sphincter overlaps and cradles the levator ani intermingling of fibres is much less striking in this species and demarcation of the muscles from each other can be made with some certainty. The 'deep' uppermost part of the external sphincter as shown in Plate 2.109 has some antero-posterior fibres which join the ano-coccygeal raphe and some annular ones deep to the above. These fibres in my opinion represent the 'sling complex' of man and form a thickening which overlaps the lowest levator fibres which join the raphe at the exact site of the ano-rectal angle (perineal flexure) which is well marked in this specimen. This finding is at variance with that of Sonntag (1923) who found the entire rectum and anal canal formed a straight tube without any trace of the flexure present in man. Certainly there are no lateral flexures or valves of Houston but the perineal flexure was well marked and maintained I believe largely by external sphincter musculature.

Perineal Musculature

The inferior fascia of the levator antero-medially forms a dense fibro-tendinous membrane which passes behind ischio cavernosus and blends with its sheath and that part of bulbo-spongiosus, which occupies the position of the superficial transverse perineal muscle in man, and this membrane strengthened by a small component from the obturator fascia dna contributions from the muscular sheaths of ischio-cavernosus and bulbo-spongiosus forms the equivalent of the perineal membrane in man.

Elftman (1932) opens a subsidiary debate on whether the deep transverse perineal muscles (and superficial transverse perineal ones as well?) might be homologous with fibres of bulbo-spongiosus which gain attachment to the ischium in so many primates and

/states ....

states that in man such fibres are sometimes present - he further asks whether such fibres when present have their usual relations to the inferior lamella of the urogenital diaphragm (perineal membrane). In one human specimen having such fibres in well marked form I was unable to find an inferior lamella (perineal membrane) but could distinguish a well defined transverse perineal muscle mass with a thickened inferior transverse bundle and a thinner upper portion arising from the sheaths surrounding the blood vessels in the pudendal canal and this muscle mass was outwardly continuous with the aberrant bulbo-spongiosus fibres. This seems a strong point in favour of this homology. In our chimpanzee specimen part of bulbo-spongiosus reached the ischium and was in the position usually occupied by the superficial transverse perineal muscle.

Innervation

The pudendal nerve and its terminal branches, dorsal nerve of penis and perineal nerve travel in a special fibrous sheath (a part perhaps of Grafton-Elliott-Smith's lunate fascia) at a higher levelthan the pudendal canal (which is very shallow on the medial side of the chimpanzee ischium). This fascia is bound to the sacro-tuberous ligament above and is slightly separated from the fascia covering the lower part of obturator internus. The inferior rectal and perineal branches reach the muscles as the nerve pursues the downward and forward course indicated in Plate 2.107. The nerves are accompanied by corresponding arteries.

Sonntag (1924)describes the pelvic floor in the orang-outang as being chiefly composed of coccygeus. The levator he says arises from the pelvic brim over the anterior half of the ilium and is inserted into the front and sides of the anus. I would very much like to see this arrangement.

6. Conclusions

With regard to the frequently stated view that the pelvic floor muscles were primarily tail movers, which have partly degenerated

/or ....

or become transmogrified to fibrous tissue, I have been convinced by Paramore's (1910) arguments and my own observations that the pelvic floor muscles develop in their own right and have only a subsidiary function as tail movers. The increase in fascia and tendon can be equated with the weight bearing function of the pelvic floor.

Thus as the vertebrates moved onto the land they developed a bony pelvis and a pelvic floor to play an important part with the diaphragm and abdominal wall musculature in regulating intra-abdominal pressure essential in respiratory excursions, venous return and all expulsive efforts as well as to snugly surround the tubes which leave the pelvis and to co-operate with sphincteric musculature in the maintaining of continence. The support of the pelvic viscera in man is the function of the pelvic fascia which increases so greatly as the upright position is assumed and is fully described in Section I.

In favour of the above contention are the following points:

i) The first muscles designed to occlude the viscera as they leave the pelvis are present from the earliest land dwelling vertebrates onwards.

ii) Tail movers to act at the best mechanical advantage are present in the long and short flexor muscles and in the extensor intrinsic musculature of the tail so that pubo- and ilio-coccygeus have only a secondary part to play in these movements.

iii) As Paramore also points out, movements of the tail of a horse or cow are as free as, or freer than that in the dog or cat, and ungulates have as much control of tail muscles or more than carnivores and yet pubo and ilio-caudalis (coccygeus) are present in the latter but completely wanting in the former. He believed that the caudo-pelvic muscles exist for one end - namely a pressure effect for they form an integral part of the internal pressure regulating mechanism which 'we should find had reached its climax in man.'

Other functions are now also attributed to the levatores ani as

/shown ....

shown in **Part** 8 but the effect of this musculature on intra-abdominal pressure is still of prime importance.

From primitive beginnings we thus reach the position as postulated by Muellner whereby intra-abdominal pressure in man is regulated by the diaphragm, abdominal wall musculature and the pelvic diaphragm and in this species selective pressure of small degree can be voluntarily directed towards either ano-rectal or urethro-vesical or vaginal regions so that relaxation of some parts of the pelvic floor can be accompanied by contracture of other pressure producing musculature to effect expulsion of contents.

Finally we are faced with the problem of whether the pelvic floor in the chimpanzee has followed a quadrupedal form or whether it shows an intermediate stage between the catarrhine monkeys and man.

In fact in man the pelvic floor muscle variation may be due to the divergent patterns shown by the catarrhine monkeys on the one hand and the anthropoid apes on the other.

ADDENDUM

Since completing this section I have found an article by Laux et al (1956). In a study of infant chimpanzee material they found branches to the external anal sphincter coming from the nervi erigentes. Their diagrams do not show the visceral branches which are offsets from the nerve to levator ani passing to the ano-rectum but otherwise are comparable. The small size of the external sphincter in their cases is doubtless due to the infant material studied and the impression of a long raphe is absent. However, the vital points he makes are completely in accord with my findings.

PART 7.

HISTOLOGY OF SLING COMPLEX AND EXTERNAL SPHINCTER INCLUDING THEIR MICROSCOPIC INNERVATION.

Photo 2.114 shows a medium power view of a horizontal section through the convexity of the horseshoe of the dissected out 'sling complex' illustrated in Photo 2.30. Plexiform interweaving of muscle fibres is striking and the formation of a raphe is suggested. Of especial interest is the branching of the muscle fibre into numerous finer myofibrils which can be seen in the centre of the field.

This specimen showed more nerves than is usual in skeletal muscle and a motor end 'point' was not demonstrable.

The second specimen which we stained for nerves was also an adult but post-mortem material was used. The sections also showed a considerable increase in innervation and no demonstrable motor end point. However, degenerative changes in the axons made the sections unsuitable for photography.

The third specimen was of a five month old infant in whom enucleation of the levator, external sphincter and terminal bowel was performed post-mortem. Horizontal sections through the 'sling complex' and external anal sphincter are illustrated and the innervation of these muscles is contrasted with that of a similar bulk of striped muscle from the limb of a six month old infant. Dr. Richard Hewlett undertook the staining for nerves at my request and the report which follows is the result of his special knowledge in this field.

Comparison of Innervation

A. Characteristic of striped muscle from the limbs is the way in which nerves supply the muscle cells at the motor point - i.e. at the equator of the muscle fibre. Thus axons run almost at right angles to the muscle cells and only small parts of the nerve are seen at a time. Photo 2.115 illustrates these points clearly. The nerve is seen to thread its way through the muscle more or less at right angles to it in this low power view. The axons are of uniform diameter until near their destinations and they seldom divide. Photo 2.116 shows an oil immersion view of a nerve traversing limb muscle. The uniformity of axon diameter is fairly

/well ....

well shown and only occasional fine fibres are seen. Photo 2.117 illustrates the appearance of motor end plates in limb muscle and the uniform diameter of fibres until telodendria arise. Arrows show motor end plates. Thus in any sample of typical skeletal muscle the nerves are usually very confined and will not be found beyond a distance of $\pm$250 N on either side of the motor point region.

B. By contrast this sphincteric musculature shows absence of a specific motor point. Axons travel for considerable distances parallel to the muscle cells and large parts of the nerve can be visualised at any one time. Photo 2.118 in a low power view shows the diffuse area of innervation and the extent of nerve visible in one field. It also illustrates the density of nerves and parallel running fibres. Photo 2.119 shows a typical long bundle of axons all visible at once. The axons tend to become thinner and thinner as they travel through the muscle. Attenuation of axons is clearly shown in Photo 2.120 and very fine axons, which are very likely to be autonomic, are abundant in this medium power field. Note the extraordinarily rich innervation quite unlike that of limb muscle. Division of axons is a prominent feature - Photo 2.121 is a lower power view which illustrates parallel fibres and multiple branching of axons. Photo 2.122 illustrates such branching in a high power view at arrow. Tremendously rich innervation is a striking feature.

In addition

i) PLEXUS formation is a most unusual feature and is not seen in limb muscles. Photo 2.118 shows this feature under medium power and Photo 2.123 shows this in an oil immersion view of a plexus in another field. Such links are numerous. This photo also shows fine fibres very clearly.

ii) A very large number of extremely FINE fibres $<$ 0.5 μ in diameter, which are likely to be autonomic in character, contrast markedly with the few fine fibres to be remarked in nerves to limb muscle.

iii) Continued branching of subterminal axons as they approach their motor end plates is unusual. It is illustrated in Photo 2.124, a medium power view, in which a motor end plate is arrowed. Photo 2.125 shows somewhat elongated telodendria in relation to

/motor ....

motor end plate at arrow. In limb muscle the telodendria tend to be short and clumped.

In summary then the outstanding characteristics of this sphincteric musculature compared with limb striated muscle are

a) Greatly increased density of innervation with the formation of plexuses

b) The very numerous, very fine, autonomic type nerve fibres.

c) The absence of a specific motor point. This may be explained as being due to annular (as well as antero-posterior) fibres consisting of either long or short overlapping units each of which has to be reached at its equator; this would mean a circular disposition of motor end plates and we propose now to identify these with a cholinergic stain. The other features noted are also of great interest.

This study is in the embryo stage but is of such promise that it will now be pursued in depth.

I believe that the key to the mysterious activity of the pelvic floor muscles lies in some, as yet undiscovered, fact about their nature. Can it be that they are a modified type of muscle, somewhere between cardiac, striated and smooth muscle, such as develop from primitive myotomes in the electric organs of fish? Or is it due to an intermingling of striated and smooth muscle on an unprecedented scale? Some such explanation must account for their unique properties, which include:

a) After complete destruction of the lumbar and sacral cord, although the muscle is paralysed, it

   i) Shows no reaction of degeneration

   ii) Responds to electrical stimulation after all other skeletal muscles have ceased to react , e.g. up to 23 years

   iii) Shows no changes histologically for long periods

   iv) Manifests twitching reactions somewhat resembling those seen in smooth muscle.

   (Hiller (1931) quoting Westphal)

b) It shows remarkable electrical activity including slow waves. See Section IV.

c) The external sphincter shows relative immunity to curare - See

/Section ....

Section IV

d) Full function remains when one pudendal nerve is sectioned.

e) Histochemical properties are of an unusual type.

f) Behaviour which fits them perfectly for their functional role, presently to be described, in relation to the viscera which traverse them.

We have been greatly struck by the unusual innervation, described and illustrated, and will continue this study using the following methods:-

i) Histochemistry
   a) Cholinesterase stains to identify motor end plates
   b) Enzyme studies.

2) Further microscopic studies of the nerves and muscle fibres
   a) with the light microscope
   b) with the electron microscope.

This approach should fully elucidate the reasons for the activity of this group of muscles.

PART 8.

FUNCTIONS OF PELVIC FLOOR MUSCLES

These muscles are supremely well adapted for their various functions because they are protected by the pelvic fascia from weight bearing and therefore can use their contractile powers to the greatest advantage. In general their functions are listed below.

1. They seal off the pelvic cavity from atmospheric pressure and so help to regulate intra-abdominal pressure. As intra-abdominal pressure rises during expiration so cranial and caudal levator fibres and external anal and urethral fibres contract slightly more to close off the anal canal and urethra.
2. They exert sphincteric control on ano-rectum, vagina and urethra.
3. By their co-ordinated actions they allow extrusion of the contents of the pelvic viscera to be accomplished with maximal facility.
4. They help maintain the important ano-rectal and posterior urethro-vesical angles.
5. By obtaining a firm hold on the walls of the two posterior pelvic organs

/and ....

and their surroundings (helped in this by the pelvic fascia and other factors) they prevent extrusion of viscera from a high pressure region to a low one during expulsive efforts.

6. Those related to their fascial coverings have been described in Section I.
7. Except during expulsive acts electrical activity in these muscles can always be recorded, varying in relation to requirements, as indicated in Section IV.
8. They take part in various reflexes which are described in Section V. The whole pelvic floor rises as a unit at the end of defaecation and micturition in a 'closing' reflex.

In particular

Levatores Ani

A. Cranial Fibres:

1. These regulate intra-abdominal pressure
2. By reason of their funnel-shape they help to move the head of the infant down during childbirth. It is considered by Smout and Jacoby (1948) also to be responsible for the medial rotation of the presenting part.
3. Cranial fibres, which are inserted circumferentially into the bowel wall, help with the shortening and widening of the canal during evacuation (very similar is this to the shortening and widening which occurs in the urethra during micturition) and at the same time, as Charles Bell put it in 1826, 'supporting it so as to prevent its being protruded'.
4. Those fibres which are inserted into the vagina and perineal body in the female, compress the vagina and help maintain the posterior urethro-vesical angle whereas in the male, although not mechanically arranged so that it could exert pressure on the seminal vesicles, it certainly elevates the prostate and thus alters the posterior urethro-vesical angle. Perhaps elevation of the prostate also compresses venous channels against the pubis as suggested in Section IV, Part 3.
5. Most cranial fibres tend to relax with the whole pelvic floor during defaecation and micturition which results in descent of

/the ....

the floor. During parturition relaxation of this muscle, which can be induced by breathing properly controlled by voluntary effort, can make the difference between relatively trouble-free delivery and puerperium and trauma which frequently brings lifelong trouble in its wake.

B. Caudal fibres

The pubo-recto-analis has an important role to play as part of the 'sling complex' which contributes to the ano-rectal ring. In this role it exerts a squeezing action which causes, with the internal sphincter component of the ano-rectal ring, a zone of increased pressure in the upper part of the anal canal, as shown by balloon pressure studies and the zone of radio-translucency, which develops with movement in this position, as described in Section IV. Electromyography, according to Taverner and Smiddy (1959), can distinguish an electrical pattern in the pubo-recto-analis of small amplitude, which varies rhythmically with respiration, when compared with that of the external sphincter. It is easy to be sure that needles or surface electrodes are in the external sphincter but it must be extremely difficult to be sure that a needle is in pubo-recto-analis and not in other levator fibres.

It relaxes concomitantly with the external sphincter and most of the cranial levator fibres so allowing the walls of the anal canal to be pulled apart by those cranial levator fibres which join them, thus aiding in defaecation. At the end of defaecation it is probably responsible, with the external sphincter and associated with relaxation of conjoined levator fibres, for the forcible contraction noted at this time which helps to empty the anal canal completely. After rectal distension has induced internal sphincter relaxation and the descent of contents into an area of rich sensory innervation it is also stimulated by the pressure of contents to contract reflexly. This is a result of afferents from the bowel and from its own muscle fibres. This empties the ano-rectal ring segment and wards off defaecation (See Section IV).

It acts as an important anchoring mechanisms of the ano-rectum having a mechanical purchase on the bowel wall out of all proportion

/to ....

to its size. It is clearly most advantageously placed for helping to

a) preserve the antero-posterior slit form of the upper anal canal and ano-rectum and

b) in the maintenance of the vital ano-rectal angle.

External Anal Sphincter

1. Because of its form and electrical activity it maintains the antero-posterior slit form of the anal canal so essential in preserving the flutter valve mechanism. It also takes part in all pelvico-abdomino-perineal reflexes.
2. Because of its relationships with the levator ani and external urethral sphincter and its own attachments it has an important anchoring function in the perineum.
3. Those fibres which form the 'sling complex' function with pubo-recto-analis as described.
4. By participating in the various reflexes noted in Section V it plays an important subsidiary role in the maintenance of continence.

Muscles of the Uro-Genital Diaphragm (Deep Perineal Pouch) and Associated Muscles acting on the Urethra.

Striated muscle, which narrows the urethral lumen, extends above the uro-genital diaphragm in both sexes and is known as the sphincter urethrae. Its action is reinforced by the deep transverse perineal muscles, which also steady the perineal body, and by virtue of the distensible cavernous meshwork and smooth muscle fibres, with which they are intimately interwoven, are able to promote closing of the urethral lumen within the urogenital diaphragm.

The bulbo-spongiosus can also act as an 'ejaculator' or 'accelerator urinae' as noted earlier.

These striated muscles all relax when the pelvico-abdomino-perineal reflex is set up at the onset of micturition and defaecation. They can relax on a voluntary basis in those who have been trained to breath correctly during labour.

The smooth muscle functions are indicated in Section II, Part 5 and in Section V. The importance of viscero-somatic and somato-visceral reflexes are indicated in Section V.

SECTION 3.

DIAGRAMMATIC ANALYSIS OF THE LAYERS WHICH CONVERGE ON THE PELVIC FLOOR

It was not possible to keep these illustrations in strict sequence.

The Peritoneum

The disposition of the peritoneum within the pelvic cavity is accurately and completely described and beautifully illustrated in most modern text books of Anatomy as well as by A.F. Dixon and A. Birmingham (1902), whose casts have only been improved on, in very recent years. Where it is in contact with pelvic viscera these are attached to it by smooth muscle strands so that it does have a slight supporting function. With peritoneum removed, the peripheral septal layers are revealed as shown in Fig. 1.1, Plate 1.2 and Fig 1.3 . Having reviewed these kindly turn to Fig 3.1.

Fig 3.1 shows the presacral, septal hammock of Waldeyer with its contents as seen at about the level of the pelvic brim in the male. Its relation to the ureter and continuity with the umbilico-vesical fascia anteriorly is illustrated. The manner in which the umbilical arteries enter the layer from the neuro-vascular pedicle behind is also demonstrated.

The fascial capsule of the pelvic colon is shown with structures in the terminal mesocolon. The attachment of Waldeyer's layer at the ano-rectal junction cannot yet be seen although the manner of fusion is easy to envisage and was illustrated in Photo 1.5 .

Plate 1.2 is for orientation then Fig 3.2 shows Waldeyer's layer in the female with its fascial investments enclosing the ureters and the manner in which it helps form most of the ligaments of the pelvis. The left half of the diagram is at a higher level than the right half.

After removal of Waldeyer's layer the recto-coccygeus or its degenerated counterpart, the fibrous ligament of Treitz, is disclosed as indicated in Plate 3.3. These structures lying above, and blending with, the fascia and muscle of the medial part of the levatores ani, fuse with the ano-rectal junction. The rectal wall and the levator ani contribute fibres to recto-coccygeus, which then continue backwards to be attached by two prongs.

/These ....

These embrace the lower part of the median sacral artery where it lies on the front of the sacrum and coccyx. Its posterior attachment is also shown in Plate 4.7.

The rest of the pelvic floor musculature is clothed by the parietal layer as described and, when this is removed, the nerves seen in relation to the levator are visible as shown in Plate 2.4.

INDEX

SECTION IV

THE VISCERA - SELECTED FEATURES
ANO-RECTUM; URETHRA AND BLADDER; VAGINA AND UTERUS

/2. ....

SECTION IV.

THE VISCERA - SELECTED FEATURES

ANO-RECTUM; URETHRA AND BLADDER; VAGINA AND UTERUS

PART 1.

ANGLES AND CURVATURES EXHIBITED BY THE THREE TUBES WHICH TRAVERSE THE PELVIC FLOOR

REMARKS ON THEIR MAINTENANCE AND OBLITERATION

1. Ano-rectum

a) Pelvi-rectal flexure

O'Bierne in 1833 is quoted by many authors as being the first to note that the rectum remains empty until just before defaecation and he postulated a sphincter at the pelvi-rectal junction, which usually lies about 15 - 18 cm. above the anus. Smout and Jacoby (1948) give a good account of the mainly horizontal disposition of the pelvic colon and its backward sweep opposite the middle sacral segment to become the rectum.

It has been suggested by Schuster (1968) that, during mass movements of the intestine, intra-abdominal pressure is temporarily increased with a rise of the pelvic floor, which blocks off the lumen of the pelvi-rectal flexure, - although attractive theoretically the anatomy of the pelvic floor muscles negates this explanation. It seems likely that a pressure difference between the rectum and pelvic colon exists most of the time as shown by waves that are of higher frequency and are present for a longer time in the upper rectum than in the sigmoid as quoted by Schuster (1968) and termed a 'reverse pressure gradient.' This and the angle, which the mobile pelvic colon makes with the relatively fixed rectum, preserved perhaps by the superior pelvic cylinder of intra-abdominal pressure postulated by Paes (1970) and helped by the 'cranial' fold of Houston (Magnus 1967) may account for the normal empty state of the rectum.

b) Perineal flexure

This ano-rectal angle is a very striking feature of the adult pelvis and is shown in most sagittal and coronal drawings in this

/thesis ....

thesis, as is the way in which the rectum surges forward from its sacral bed, before sharply kinking downwards and backwards.
In Photo 4.1 a very striking angle is seen in a parasagittally sectioned adult male pelvis. Waldeyer's layer of fascia can be seen joining the ano-rectal junction thus acting as Gabriel's 'suspensory ligament of the rectum.'
Photo 4.2 is of a parasagittally sectioned, 14 week-old female foetus divided to the right of the midline. In the foetus and infant the anterior part of the angle is well developed because it depends on attachment of the longitudinal coat of the bowel to the perineal body as illustrated in this view. The very short anal canal and the slender muscles in this age group however make it a less striking feature, although in some, a well defined angle can be seen.

All the factors described in Part II which anchor the ano-rectal junction tend to promote the angle especially the perineal body anteriorly and the 'sling-complex' postero-laterally.

It seems that it is of supreme importance in protecting the 'flutter valve' mechanism because, as Parks et al (1966) has suggested, the upper aperture of the anal canal is in direct contact with the mucosa of the anterior rectal wall so that when intra-abdominal pressure rises mucosa is driven onto the upper anal canal to form a flap valve. Intra-abdominal pressure I think would have difficulty in acting round the circumference of the bowel in the manner indicated by Phillips and Edwards (1965) because of the peritoneal arrangements in the pelvis. Reconstruction of this angle, by operations and other measures designed to restore continence, which are critically reviewed in Section V appears to play an essential part in the successful outcome of such procedures. During defaecation both the pelvi-rectal and perineal angles are largely straightened out.

c) Lateral Curvatures/Flexures

These are not usually apparent in the foetal and newborn rectum but appear during childhood and are usually well marked in adult life, two having a convexity to the right and one to the left. Related to the indentations between the flexures and, in some instances in other places as well, the submucosa becomes thickened and invaded

/successively ....

successively by circular and often longitudinal muscle coats and, in some, by peri-rectal tissue as well, to form projections into the lumen which Silver (1955) has compared to 'horizontal baffle plates'.

Much careful research into these enigmatic folds, which Houston first named in 1830, has been conducted and there are still some points which need clarification. Some of the difficulties arise from orientation, nomenclature and measurement, the rest are enshrined in Pennington's (1900) statement that the valves of Houston are not 'regular in number or location or size or position nor capacity nor structure'. 'Direction with reference to the axis' of the intestine is however nearly always horizontal and not irregular as he suggests.

Silver (1955) made a very fine study of the valves in the human foetus confirming that they may first appear during the third month of embryonic life which substantially corroborates Johnson's (1914) findings in relation to these plicae transversales recti.

Magnus (1967) in a study, which confirms much which older studies have revealed, made the fascinating observation that the folds of Houston are infrequently present under the age of two years.

The most commonly present fold found in 74% of her specimens is at the level of the base of the bladder and she recommended that it should be called the 'vesical fold'; when only one was present it lay on the anterior rectal wall but, if more than one was present, it lay anywhere on the circumference of the rectal wall. In 65% there was another fold, which she termed 'cranial', above the 'vesical' one and in 15% it was the only one. Half the cranial folds were at the recto-sigmoid junction and the rest between this level and the bladder base. In 26% a fold was found below the bladder base and was termed 'caudal'.

Three valves are frequently present in the adult and a fourth is occasionally present. Silver (1955) found, and dissecting room studies confirm, that two are often mainly on the left at the upper and lower extent of the left convexity and one is mainly on the right between them and sited at the angle where the two right convexities meet.

Magnus (1967) avoids siding of these folds because of their variable relationship to the bowel circumference but the relation of the valves to the lateral flexures, as so often seen in dissecting room

/specimens ....

specimens, can be equated with her 'cranial', 'vesical' and 'caudal' folds.

Folds are apparently invariably present after the age of two years which of course suggests an important link between their development and the assumption of the upright posture.

Despite Schuster's (1968) statement incontrovertible evidence has been presented by Silver (1955) and Magnus (1967) which show that larger folds contain longitudinal muscle as well.
Because these folds are only found in 25% of specimens examined during the first year of life, and when present may be 2 to 3.5 cm. from the anal verge, Magnus (1967) feels that the Shandling technique in the diagnosis of Hirschsprung's disease is of questionable value.

Whereas Houston and Silver (1955) both believe that the folds can be obliterated by distension of the rectum, Magnus (1967) claims that, as they are solid structures, produced in the first instance by gathering and then thickening of the circular muscle layer, they cannot be obliterated by straightening the bowel wall.

Their function in supporting faecal matter and preventing it from distending the lower part of the rectum and thus giving rise to the desire to defaecate was postulated by Houston and quoted by Magnus (1967). As this is borne out by sigmoidoscopic findings it seems highly probable, as does the folding up of the empty bowel after the act, proposed by Magnus.

It would seem that in relation to their obliteration the sequence of events may well be that as the pelvic floor descends a partial straightening out of the rectum occurs with a diminution in the size of the folds and that as the longitudinal coat contracts to widen the lumen and increase intrarectal pressure a further decrease in the prominence of the folds would be effected. Betweenwhiles the shelf-like structures with their intrinsic tone act as a barrier to the downward passage of contents but can be easily pushed aside by a sigmoidoscope. Further confirmation of this function is provided by pressure studies cited by Schuster (1968), which show that zones of increased pressure in relation to the valves are recorded when balloons are withdrawn through the rectum. This is due to the resistance to their passage offered by

/these ....

these structures.

Finally, in relation to these valves Bauer (1863), quoted by Silver (1955) looked in vain for valves in wolf, bear, wombat, Semnopithecus Maurus, Lemur Tardigradus, Cebus Opellus, Jemia Troglodytes and rhinoceros and Magnus has failed to find them in Monotremes, Marsupials, Cetacea, Carnivora, Ungulata, Rodentia, Langomorpha and some Primates. She adds the Cynamologous monkey to Bauer's Lemur tardigrada with the same result and they were absent in three baboons and the chimpanzee which I examined.

These negative findings, taken in conjunction with their constant development in man concomitant with the development of the upright position, shows, I think, that when one adopts, as I have been forced to do, a multifactorial approach to continence, these folds must be considered to play a small but significant part in its maintenance.

2. Urethra

a) Angles in Female

The proximity of the female urethra to the pubic symphysis and arcuate sub-pubic ligament was especially noted by Curtis et al (1942) and is shown in Photo 4.3 and Photo 4.4.

Photo 4.3 is of a sagittally and coronally sectioned female pelvis with a very short urethra. The bladder has been freed from its pubo-vesical/urethral ligament.

Photo 4.4 is of an eight month female foetus sagittally sectioned. Krantz (1951) in a study, which had no bibliography or references attached, but clearly involved a great deal of work, described plastic reconstructions from 41951 serial sections. These demonstrated the relations of urethra, bladder and vagina to each other and showed that the urethra assumes an angle of 16° from the internal urinary meatus to the external urinary meatus against the anterior vaginal wall. Green (1962) estimates that the angle between the axis of inclination of the upper urethra and the perpendicular is about 30°.

Posterior Urethro-vesical angle

To Roberts and Jeffcoate (1952) goes the credit for, not only

/observing ....

observing that the angle formed between the posterior wall of the urethra and the trigone of the bladder is normally between 90 and 100°, but appreciating the enormous importance of this angle in the maintenance of continence. This will be considered later when operations and other measures, which aim to preserve or restore urinary continence, are described. This angle is usually visible in the cadaver and is shown in Photo 4.3 and Photo 4.5.

These angles are maintained largely by the anchoring mechanisms of the urethra, bladder, vagina and uterus which are summarised in Part 2. Because levator fibres intermingle with vaginal wall musculature as well as passing into the perineal body contraction of the levator lifts the vagina and therefore the urethra, which is embedded in its anterior wall, forwards thus helping to maintain the posterior urethro-vesical angle.

During normal micturition the posterior urethro-vesical angle completely disappears. It does this because cystourethrographic studies have shown that it, and the trigone, straighten out between a lower fixed point in the uro-genital diaphragm and an upper fixed one at the top of the bladder base. This region, with nearby internal os of the cervix, have been found to remain constantly related to a line joining the lower border of the pubic symphysis and the junction of sacrum and coccyx. The pubo-vesical/urethral ligaments must be important in maintaining this relationship as well as the other anchoring factors noted.

b) Angles in Male

There is a clearly defined forward inclination of the urethra as it passes into the bulb. This is shown on sagittal section of the pelvis and is confirmed by urethro-cystographic studies. Photo 4.5, which shows a dilated prostatic urethra, illustrates this angle in the adult and Fig. 4.6 in the foetus in the only case in which, I think, sling fibres, which might be termed pubo-urethralis, are present. Unfortunately the specimen is missing so I cannot obtain histological confirmation of this impression. The posterior urethro-vesical angle is similar to that seen in women and is largely maintained by the anchoring mechanism mentioned in Part 2.

/3. ....

3. Uterus and Vagina

Many authoritative works have described, and all studies confirm, the normal 70-90° angle between the cervix and vagina when the bladder and rectum are empty. Likewise anteflexion of the body of the uterus on the cervix is generally accepted. These angles are partly maintained by the anchoring mechanisms described in Part 2 and partly are innate structural entities.

Mengert (1936) found retroversion of the uterus in 65% of women confined to bed with tuberculosis, who lay mainly on their backs. Over 1-5 days the uterus reverted to an anteverted position as a result of these patients lying in a mainly prone position. Gravity therefore plays an important role in maintaining anteversion in the erect position.

In addition it is well known that the uterus frequently inclines towards the right side bringing the uterine artery and ureter into a closer relationship with the lateral fornix of the vagina and cervix on the left than on the right. No explanation of this inclination, which only develops in adult life, is offered. Rotation of the uterus to the right after the fifth month of pregnancy may be an explanation in parous women.

The fact that procidentia never develops when the normal angle is preserved between cervix and vagina and hardly ever when the uterus is retroverted, suggests that this angle also acts to prevent the protusion of the distensible vaginal tube from the high intra-abdominal pressure zone into the low pressure area of the exterior unless the axis of the viscus is such that evagination is favoured.

PART 2.

ANCHORING AND SUPPORTING MECHANISMS

1. Ano-rectum

a) Summary of Anchoring Mechanisms

The way in which the ano-rectal region is tethered to its surroundings by fibro-tendinous, fascial and muscular connections are described in some detail elsewhere (Wilson (1967)). The rather numerous anchoring

/and ....

and supporting mechanisms may be listed in tabular form as follows:-

Anterior:

I Perineal body

II Recto-urethralis

Posterior and lateral:

I Superior fascia of levator ani

II Substance of levator ani forming wholly or in part

1. Pubo-recto-analis
2. Conjoined longitudinal coat
3. Ano-coccygeal raphe

Posterior:

I Blended fascial elements

1. Superior fascia of levator ani
2. Waldeyer's fascia
3. Fibrous (Treitz) and fibro-muscular structures (recto-coccygeus syn. sacro-rectalis) between sacrum and coccyx

II Stratified ano-coccygeal raphe

1. Pubo-coccygeus
2. Ilio-coccygeus
3. External sphincter

Superior:

I Peritoneum and attachments affording remote control

II Ant. recto-vaginal/vesical septum (Denonvilliers) P.

III Post. Waldeyer's fascia

IV Tela subserosa and contents

Inferior:

I Inferior fascia of levator ani continuing into ANAL fascia.

II Funnel formed by interlacing of pubo-recto-analis and external sphincter which surrounds ano-rectal region

III Coat-tail terminations of conjoined longitudinal coat interlocking bowel with environs

IV Gluteus maximus and ischio-rectal fat and fibrous septa.

/Most ....

Most of these features have been described in the relevant section of the thesis and I shall now summarise the main anchoring arrangements and draw attention to those not otherwise included in the text.

The most important anchoring factors are the perineal body, presently to be described, components (including fascial) of the levator ani and external sphincter especially in their relationship to:-

1. The conjoined longitudinal coat Part 6.
2. The 'Sling Complex' Section II
3. The stratified ano-coccygeal raphe.

b) The Perineal Body

This important fibro-muscular structure lies between the rectum and urethra in the male and the rectum and vagina in the female, in whom it is smaller. It is shown in Plate 4.7 and Photo 4.8 among others. Looked at from its cranial aspect it has a rectangular form and we find that:-

1) Its anterior corners and lateral aspects receive fibres from
    A) most anterior fibres of pubo-coccygeus as shown in Photo 4.8 and its epimysial fascial sheath i.e. the superior fascia of the levator.

    The muscle fibres constitute well known levator glandulae prostate and sphincter vaginae fibres, as well as less well known PRE-RECTAL fibres, which were described in Section II. The superior fascia has also been described in this region in Section I.
2) Its posterior and lateral corners receive prongs of recto-coccygeus muscle or the fibrous ligament of Treitz in most specimens as shown in Plate 3.3.
3) Its upper surface is joined by the recto-vesical/vaginal septum already described and illustrated, and
4) Into its posterior upper border pass fibres from the longitudinal coat of the anterior wall of the rectum. They are visible in Photo 4.8. These fibres I believe are most important in maintaining the ano-rectal angle (perineal flexure). Some fibres arising in this way form slender bands which pass forward towards the urethra and constitute the superior recto-urethralis muscle.

/From ....

From the anal canal a few fibres, which are termed the inferior recto urethralis, pass to the perineal body and urethra in front, of it. Recto-urethralis fibres are shown in Fig 4.6 , Plate 4.7 and Photo 2.55. I cannot agree with Kohlrausch, quoted by Uhlenhuth (1953), that these fibres act as an adductor prostatae, which press the prostate and therefore the veins of Santorini against the pubis during erection, although the levator glandulae prostatae muscle might do so.

The perineal body has also an appreciable vertical extent so that, passing from cranial to caudal, it gives attachment to the muscles in the deep perineal pouch before reaching the perineum.

Caudally, in the superficial perineal pouch, it forms a slender hub, from which radiate many fibres of the external anal sphincter, the superficial transverse perineal muscles and a few fibres of the bulbo-spongiosus muscle, in relation to which, the perineal body becomes firmly attached to the middle of the posterior border of the perineal membrane.

It thus forms a vital welding link between the pelvis and perineum and anchors the anterior ano-rectum to the pelvic bones. Its essential contribution to the stability of the pelvic floor is unlikely to be overlooked but Figs 20.41 and 20.42 in 'A Companion to Medical Studies'(1968), a most up to date textbook, contrast rather surprisingly with what is found in the body.

c) The Raphe

The stratified ano-coccygeal raphe has an upper stratum (above which is the muscle and ligament of Treitz), receiving pubo-coccygeal fibres, middle strata receiving contributions from ilio-coccygeus and the 'sling complex', and lower strata which receives fibres from the 'superficial' and 'subcutaneous' parts of the external sphincter. In most specimens a plane of separation, referred to earlier, is present between the sling complex and the lower strata of the raphe. Very occasionally a gap exists above the sling complex and below cranial levator fibres. This condition is illustrated in Fig 4.9 which shows again how variable muscle arrangements in this region may be. The space of Courtney is shown in Plate 4.7.

/Courtney ....

Courtney (1949) suggests that the name ano-coccygeal raphe is a misnomer with which statement I cannot agree. Some of his illustrations are difficult to follow and the names corresponding with some of the numbers are missing from Figs 1 and 3. Parks (1969) omits any reference to gaps in the raphe when considering horseshoe abscesses.

Complex branching and imbrication of muscle fibres in this region are illustrated in Section II Part 6 and in Photo 2.33. This important, layered scaffold firmly anchors the ano-rectum posteriorly and contributes substantially to the maintenance of the ano-rectal angle. The decussation of levator fibres seen in the raphe would tend to promote the slit like form of the anal canal.

d) Support from Ischio-Rectal Fossae

Walls (1963) quotes Mackintosh and Shellshear as pointing out that, because of pelvic obliquity, the base of the ischio-rectal fossa is directed more posteriorly than inferiorly, and therefore that, as gluteus maximus closes in the fossa posteriorly, it can, by exerting pressure on the ischio-rectal fat, act as an additional support for the pelvic viscera. Fibrous septa, shown in Plate 1.6 and Photos 4.10 and 4.11, traverse the ischio-rectal fossa and so reinforce the arrangement. These partitions account for the loculation and painful nature of ischio-rectal abscesses.

Photo 4.10 shows the ischio-rectal fossae in a female foetus for orientation.

Photo 4.11 shows these fibrous septa in detail. The photo is of a section just cranial to 4.10 and is taken through a filter to get good contrast. Above is gluteus maximus, below are hair follicles and to the extreme right is the external anal sphincter. Their statement that gluteus maximus is attached to the ano-coccygeal raphe is not true in man so that it is only the portion medial to, and arising from the sacro-tuberous ligament, which could exert this effect.

e) Conclusion

As I have stated before 'the thin, resilient fabric woven round the ano-rectal region, though of variable pattern, is positively welded

/to ....

to its surrounding pelvic framework and only with prolonged use, abnormal pressure or actual trauma does it fray, sag or give way altogether' Wilson (1967).

2. Urethra and Bladder

a) Male

Prostatic - membranous urethra

The membranous urethra is fairly firmly tethered within the deep perineal pouch and as it passes into the bulb, which is attached by bulbo-spongiosus to the inferior aspect of the perineal membrane. The prostatic part is embedded by the gland, which is firmly held by its fascial capsule, containing its venous plexus, to the superior fascia of the levator anteriorly and laterally and via pubo-prostatic ligaments above to the pubic bone as described previously. Behind, the fascial layer of Denonvillier gives support to the prostate. All these features are shown in Plate 4.7.

Extending from a point just below the prostatic urethra downwards behind the membranous portion is the perineal body. Into this passes part of the superior fascia of levator which also joins the urethral wall in relation to the upper layer of the urogenital diaphragm and the levator glandulae prostatae fibres which support, elevate and depress the prostatic part of the urethra. Invasion of this muscle by carcinoma of the prostate leads to incontinence because the important posterior urethro-vesical angle cannot be maintained.

The urethra in the male, just below the apex of the prostate, lies very close to the ano-rectum only separated from it by the perineal body and not as shown in Fig 4 by Naunton Morgan (1949). See Photo 4.8 which shows the cut urethra just anterior to the perineal body and the cut ano-rectum immediately behind it. Cranial levator fibres can be seen framing these structures.

Bladder

The bladder is anchored as described in Section I along its infero-lateral aspects by the pubo-prostatic and lateral ligaments of the bladder and along its lateral borders by the anterior septal umbilico-vesical layer of fascia, which invests the urachus and

/obliterated ....

obliterated umbilical arteries as they pass up to, and become attached to the umbilicus. Below it is firmly united with the prostate at the vesical neck. Posteriorly it is supported to some extent by the ureters embedded in umbilico-vesical fascia and Waldeyer's layer and by the seminal vesicles and vasa and fascial layers related to them. The superior surface is free to expand and push its covering of peritoneum upwards.

b) Female

Urethra

Posteriorly the lower two-thirds of the urethra is embedded in the anterior wall of the vagina and the upper one-third is enmeshed by utero-vaginal fascia. Anteriorly it is held to the pubis by pubo-urethral/vesical ligaments. The closeness of this relationship was well seen in Photo 4.4 and Fig 1.9. In the enormous interval left for it, anterior to the perineal body, no urethra is shown in Figs 20.41 and 20.42 in the 'Companion to Medical Studies' (1968) previously referred to. Laterally and anteriorly, it is invested by the superior fascia of the levator. Above, it is attached to the bladder and below is held within the urogenital diaphragm.

Bladder

Anteriorly and laterally are pubo-vesical and lateral ligaments of bladder. Photos 1.33a and 1.33b illustrated the left pubo-vesical/urethral ligament as seen in the female neonate. Posteriorly is utero-vaginal fascia. Along the lateral border is the umbilico-vesical layer with its extension round the terminal ureters and upward sweep to the umbilicus. Behind the level of the round ligaments of the uterus the ureters are invested, as in the male, by Waldeyer's fascial layer.

3. Vagina and Uterus

Peritoneal folds which form some measure of support to these organs are:

i) utero-vesical fold)
ii) recto-vaginal fold) of peritoneum
iii) recto-uterine folds)
iv) broad ligaments of uterus

/Connective ....

Connective tissue and smooth muscle form the general embedding material, the condensations known as ligaments, and the anchoring sheets, which are described under the headings parietal, septal and visceral layers of pelvic fascia in Section I.

By virtue of the close relationship of urethra and vagina this includes the attachment afforded by the pubo-vesical/urethral ligaments to the pubis.

As noted earlier the sphincter vaginae portion of the levator ani, joining the vaginal wall and passing to the perineal body behind it, can move the vagina and therefore the urethra forward, thus altering its important posterior urethro-vesical angle. This levator attachment is doubtless a most important anchoring factor.

Posteriorly the vagina is bound to the perineal body. Inferiorly deep pouch musculature, erectile tissue and related musculature, help support the viscus.

Torsion of the uterine tubes is of exceptional occurrence and is nearly always associated with a bifid uterus. In the veterinary literature torsion occurs not infrequently and is associated with the lack of anchoring accompanying uterus didelphus.

PART 3.

VENOUS PLEXUSES

The venous networks in the pelvis really defy description and a glance at the magnificent pictures in Grant's Atlas (1962), Pernkopf (1964) and Netter (1962) and Gray (1967) will show something of their complexity.

The vesical, prostatic and vaginal plexuses and their communications with the venous channels of the erectile tissues are well documented. Uncommonly remarked, if mentioned at all, are the abundant plexuses, which occupy the urogenital diaphragm. They communicate with internal pudendal venae comites principally and through these with the dorsal veins of penis or clitoris and so reach the pelvic venous plexuses.

The internal haemorrhoidal plexus has also been most carefully analysed and described and the literature on haemorrhoids is of course prolix. The external haemorrhoidal plexus and the perineal haematomata which may follow rupture of these veins are also well known entities.

/As ....

As one dissects out these multichannelled, bulbous, ramifying vessels, which so often obscure fine nerves and arterial twigs, one has plenty of time to reflect on the purpose of such remarkable apparent superfluity. Clearly in the female the channels act as a reservoir and like the arteries are tortuous enough to be able to elongate during pregnancy and freely convey the enormous increase in blood which passes through the uterus at this time.

And in both female and male the engorgement of erectile tissue supplies another reason for such channels.

But considering the rather striking analogy between the ano-rectal region and the oesophagus pointed out by Edwards (1961) and Phillips and Edwards (1965) it is interesting to find that here too a prominent submucosal plexus of veins, also given to haemorrhage, is present.

This leads one to wonder whether these spongy distensible, low pressure cushions sited

i) In ano-rectum - One such channel is shown in Photo 4.27

ii) In the membranous urethra these are shown in the submucosa in Photo 2.78.

iii) In the urogenital diaphragm - see Photos 2.66, 2.67 and 2.68.

iv) In the cervix, illustrated in Photo 4.12, where it lies normally in the tunica propria especially beneath the stratified squamous epithelium of the portio vaginalis. It increases considerably and gradually forms a huge cavernous mass like an erectile body during gestation - (Smout and Jacoby (1948)).

are not all acting in a subsidiary capacity to help close the various canals, in whose walls they are sited, or round which (urogenital diaphragm), they are disposed.

The advantage of such channels is of course that they can be flattened and obliterated by contents passing through the canals. Such a function for the internal haemorrhoidal plexus was proposed by Didio and Stieve (1968) but it seems equally likely to be applicable to the above sites as well. Didio (1968) suggests that children are unable to control defaecation until the haemorrhoidal venous plexus has developed. This clearly does not stand up to critical examination.

PART....

PART 4.

GROSS INNERVATION OF PELVIC VISCERA

The pelvic organs, as is well known, receive their innervation via the pelvic (inferior hypogastric) plexuses which are formed by the union of sympathetic and parasympathetic fibres.

Sympathetic fibres, from lower thoracic and upper lumbar reaches of the cord, pass via lumbar ganglia, pre-aortic and inferior mesenteric plexuses in front of the fifth lumbar vertebra and promontory of the sacrum to form the (superior) hypogastric plexus. These nerve fibres are embedded in Waldeyer's layer of fascia and inferiorly fibres to each pelvis plexus pass, with many cross communications, to the network, which is especially well seen in the foetus between the ureter and the lateral wall of the rectum as illustrated in Fig 1.6 and 1.7. Knotted ganglia are prominent features of the pelvic plexus which is not of a uniform size and shape in children or adults.

The largest of the ganglia is known as Frankenhauser's or the Cervical ganglion (Curtis et al (1942)). Part of it is illustrated in Photo 4.24.

It is believed to consist of adrenergic neurones as described later.

From the sacral chain, especially from the second, third and fourth ganglia additional sympathetic fibres reach the pelvic plexus.

The ano-rectum receives an additional sympathetic supply from the pre-aortic and inferior mesenteric plexus which distribute fibres along the superior rectal vessels.

Parasympathetic fibres pass as the pelvic nerves or nervi erigentes (pelvic sphanchnics) via 4-6 stout contributions to the pelvic plexus, which come mainly from S.(2)3 and 4(5). They pass forward into Waldeyer's layer in which they remain.

The bowel receives additional parasympathetic innervation from two sources.

Firstly, direct offsets consisting of 3-5 fine twigs, which pass through Waldeyer's directly to the postero-lateral bowel wall at the level of the ischial spine, have been repeatedly shown in dissections. They arise usually from 2, 3 and 4 but in two specimens they arose from S2 as well and in three from S5. These fibres reach the bowel wall about 4 cm. from

/the ....

the ano-rectal junction in the fixed adult cadaver.

Secondly via branches from S3 and 4, first described by Telford et al (1934), which ascend directly, as shown by Mitchell (1953), or traverse the hypogastric plexus and lower part of the pre-aortix plexus, to reach the inferior mesenteric artery and so the hind gut. Some of these fibres descend with the superior rectal artery to the ano-rectum. Direct offsets to the uterus and vagina and to the bladder are sometimes present - Mitchell (1953).

Fig 4.13 is the key to Photo 4.14 and shows fibres from S3, 4 and in this case S5 joining the pelvic plexus with some fibres reaching the bowel wall directly. Fibres passing from the sympathetic chain to the plexus can also be seen. Photo 4.15 shows a closer view of some of these fibres. Photo 4.16 shows bowel pulled forward and to the left with parasympathetic fibres from the right passing to it. The sympathetic chain, which has been freed, is seen to lie medial to sacral nerves on the left pelvic wall. Part of the perineal branch of S4 can be seen crossing coccygeus.
Photo 4.17 shows a sagittally cut male pelvis. The relationship and extent of the left pelvic plexus is suggested as is the tethering of the ano-rectum below. To the right the urethra and ejaculatory duct can be seen and anterior to the rectum is Denonvillier's fascia.
The position of the pelvic plexuses in shown in Figs 1.6 and 1.7.
From the pelvic plexuses, which are beautifully illustrated by Mitchell (1953), Netter (1962) Grant's Atlas and if somewhat idealistically, by McKrea and Kimmell (1952) branches pass:

a) to the pelvic organs
b) via visceral branches of the internal iliac to pelvic and perineal structures. These fibres, which accompany pelvic bloodvessels, have been shown to be probably almost exclusively sympathetic in nature (Mitchell,(1953)). Fibres reaching the ano-rectum, the internal genital organs and the bladder are easy to see. Most fibres in relation to the bladder pass below the ureters, though some loop round them. In Photo 4.18 part of the terminal ureter cut longitudinally is seen in the centre of the field. On each side numerous nerve bundles are visible. The bladder lumen is

/above ....

above and to the right. From here fibres spray upwards onto the superior surface and others pass to the trigone, vasa, seminal vesicles and prostate.

The recto/vesical/vaginal septum carries a number of autonomic fibres as shown by Silver (1956).

Depending on the area supplied, names, such as 'rectal', 'vesical' and 'utero-vaginal', have been attached to various portions of the plexus, but, as it lies in a curved fascial hammock and is made up of an inextricably mixed collection of fibres, I believe these names are not justifiable.

McKrea and Kimmel (1952) described additional parasympathetic nerves passing to the bladder which, they said, maintained a close relationship to the pudendal plexus.
I think the nerves they describe must be the long cavernous nerves or the occasional direct offsets to the bladder, which travel in Waldeyer's layer on the lateral edge of the pelvic plexus to the cavernous tissue and bladder. In a second article (1952), largely repeating the first, they now admit that sympathetic fibres are also contained within their 'accessory' nerve pathways. They are, perhaps, the same fibres, which Smith and Ballantyne (1968) note as passing outside the pelvic fascia.

In describing the innervation of the bowel Connel (1969) does not mention sacral chain fibres joining the pelvic plexus, or the parasympathetic fibres which pass directly to the bowel wall. He also remarks that the descending and sigmoid colon receive sympathetic fibres from the thoracolumbar outflow 'although it receives some vagal fibres via coeliac and aortic plexuses.''.

Functional Aspects

Wells et al (1942) showed that electrical stimulation of the vagus nerve was ineffective in producing contraction of the hind gut. They proved the cholinergic nature of the pelvic nerves and the adrenergic nature of the hypogastric fibres.
Gillespie and MacKenna (1961)demonstrated the inhibitory action of sympathetic nerves on smooth muscle in the rabbit gut and its reversal by reserpine and restoration by soaking the bowel in adrenaline, nor adrenaline and DOPA.

/Proof ....

Proof that the nervi erigentes are cholinergic is evidenced by the fact that their action is inhibited by atropine, mimicked by acetyl choline and potentiated by physostigmine.

Goligher (1951) quoted evidence indicating that, whereas small intestinal and colonic pain is carried by sympathetic afferents, his own investigations proved conclusively that neither sympathetic nor somatic pathways carried the sensation of rectal fullness, which is conveyed exclusively through sacral parasympathetic afferents.

The findings of Garrie and Gillespie (1955) and Garrie (1957) in relation to stimulation of autonomic nerves reflect the delicacy of autonomic balance; thus stimulation of the pelvic parasympathetic nerves in rabbits led to colonic contraction whereas stimulation of lumbar sympathetic nerves induced colonic inhibition. However low frequency stimulation of both led to a pure motor response and high frequency stimulation of both produced pure inhibition. Intermediate frequencies administered to both led to alternating contraction and inhibition. Their work gives some idea of the complexity of the system.

Garrie and Mack (1964) noted that stimulation of one pelvic nerve caused contraction of the smooth muscle of the whole circumference of the bowel wall.

Fairly conclusively proven is the vaso dilatation in this region produced by parasympathetic fibres and the vaso-constriction produced by sympathetic fibres (Mitchell, (1953)). Contraction of the trigonal musculature and blanching of this region, correlated with a rise in blood pressure to 210 mm Hg, was observed by Learmonth (1931) when he injected intravenous adrenaline into a patient with vesical exstrophy.

According to Gillespie and Mack, quoted by Schuster (1968) with an incorrect reference, the internal sphincter receives an inhibitory parasympathetic supply and an excitatory supply from the sympathetic system. Stimulation of the hypogastric plexus causes internal sphincter contraction whereas stimulation, after injection of ergotoxine, caused relaxation. This response needed intact rectal receptors to initiate it. This is proved by its persistence after cord transection or damage to sacral nerve roots and its loss after 'pull through operations' which have removed too much mucosa.

/Both ....

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/Both ....

Both afferent and efferent fibres are contained in these plexuses and their endings in the viscera will be referred to as each viscus is considered in the next part of this study.

PART 5.

GANGLIA AND NERVE ENDINGS

1. Terminal Bowel

This is an enormous subject of the greatest interest and importance on which only a very few general remarks will be made.

a) Ganglia

Bodian et al (1951), Yntema and Hammond (1952, 1953, 1954) and Okamoto and Eudi (1967) claim that all the neuroblasts of the myenteric and submucous plexuses are of vagal neural crest origin and proceed in a cranio-caudal direction down the whole gastro-intestinal tract. Andrew (1969) produces evidence which shows that, as trunk neural crest and/or tube has the potentiality to give rise to ganglion cells, some of these probably arise from this source. She does not, however, dispute the possibility that most neuroblasts in the tract may be derived from the vagal neural crest.

Her evidence is based on culture, as chorio-allantoic grafts, of pieces of blastoderm of chick embryo between 13 and 25 somite stages, which were delimited to include and/or exclude neural crest and/or tube, at defined cervical and trunk levels.

Indisputable evidence is given that caudal and cranial trunk and caudal cervical levels can give rise to enteric ganglion cells. She feels therefore that it seems likely that the ability would be realised in normal development. Her criticism of Yntema and Hammond's experiments rests on the time at which their operations were performed because pigment cells and enteric ganglion cells migrate away from the cord at a much earlier stage than those which form the cells of the paravertebral sympathetic trunks and the prevertebral plexuses. Precursor ganglion cells first reach the presumptive gizzard and intestine of the chick embryo at or very shortly after the $12\frac{1}{2}$ somite stage which is attained at approximately 40 hours incubation. This is earlier than the time at which Yntema et al examined their embryos

/and ....

and formed their conclusions.
Jones (1942) shows pictures of Remak's ganglion and well developed enteric ganglion cells in the rectum of an eight day old chick. These features were absent from a seven day old chick from which the caudal end of the neural tube was removed at 48 hours. His evidence supports that of Andrew.

Okamoto and Eudi (1967) found, in six week human embryos, that neuroblasts were present in the myenteric area of the cardia but that there were none in the rest of the gastro-intestinal tract - By seven weeks they had migrated to most of the cephalic limb of the mid-gut loop; by eight weeks all except the distal half of the colon and rectum had cells and, by twelve weeks, all parts of the tract had ganglia. They show very convincingly that cells first develop in Auerbach's myenteric plexus and then migrate in to the submucosal one of Meissner.

Truelove (1966), in a review article, states that in man the myenteric plexuses may be relatively concentrated in the region of the taenia of the large bowel, although a thin smooth longitudinal coat does extend between them as shown by Hamilton (1964). More ganglion cells are found in the distal bowel than the proximal and the rectum is most richly supplied. Some ganglion cells are also found in the adventitia of the bowel.
Aldridge and Campbell (1968), in a meticulous study of ganglion cells in the normal rectum and anal canal, found that in general Auerbach's plexus extended lower than Meissner's plexus. They subdivided Meissner's plexus into a superficial and deep submucosal plexus depending on the relationship of the cells to the muscularis mucosae.

They saw no ganglion cells below the line of the valves and noted that an area 1.7 cm. above the valves had very scanty submucosal ganglia. They termed this a 'hypoganglionic' zone.
Associated with areas of sparse ganglia there are large nerve bundles, which are indistinguishable from the 'hypertrophied' nerve trunks found in the ganglionic segment, in some cases of Hirschsprung's. These are probably normal.

It has been proved that Bayliss and Starling's Law of the Intestine, whereby excitation of the gut causes contraction above, and relaxation

/below ....

below, the point stimulated, is due to the myenteric plexus as it still occurs when the submucosal plexus is removed. Hukuhara, quoted by Truelove (1966) has also noted that *stretch* of the longitudinal muscle coat produces two reflexes, one being intestino-intestinal via sacral cord and nervi erigentes, the other being an intrinsic reflex involving the myenteric plexus.

Pacemaker activity in the gut shifts from place to place unlike the arrangement in the heart. It is much more sensitive to stretch than cardiac muscle. (Bullbring quoted by Fallert (1968)).
This very recent work was presaged by Sir Arthur Keith in 1915 who wrote of food being 'propelled through a series of zones or segments, each furnished with its own pacemaker and its own rhythmical contractions.' He proposed that irregularities or blocks might occur in the nodal or conducting system of the alimentary tract especially at sphincteric zones. He brought to the forefront the musculature of the alimentary tract as the sole propelling power in the intestinal wall, whose faulty function resulted in enterostasis. He firmly but politely discounted the 'drag, band and kink' theory propounded by Arbuthnot Lane.
In the same dissertation he drew attention to Bayliss and Starling's 1899 discovery of the intrinsic beat of bowel muscle even in vitro in which two separate rhythms could be distinguished - a slow and a fast one.
As Connel (1969) has shown, even computerisation has not solved all the complexities of electrical activity and associated movements of bowel musculature.
Kerreman's (1969) quotes Bortoff (1965) as stating that circular muscle 'does not exhibit the spontaneous rhythmical contractility' characteristic of intact intestine or of longitudinal muscle. It appears that this property is intrinsic in longitudinal muscle and induced in circular muscle.' Kerreman's (1969) *in vivo* investigation of isolated, circular smooth muscle of the internal anal sphincter has shown it to be unlike other circular muscle in that it has spontaneous activity. His observations on *in vitro* strips of isolated internal sphincter led him to the conclusion that several pacemaker mechanisms

/are ....

are involved in the spontaneous activity of the internal sphincter. He believes there are functional differences between the upper and lower parts of the internal sphincter based on the relative fixation of the upper part by coat-tails traversing it and the relative diminution in number of such entities in the lower portion.

Photo 4.31 is a transverse section above the ano-rectal ring in the five month infant whose sphincteric nerves were illustrated. To the left is rectal lumen. Well defined circular and longitudinal coats are visible with between them the ganglion cells of the myenteric plexus. Sub-mucosal ganglia are less striking but are present.

Pathology

Colonic motility is apparently increased by aggressive and hostile feelings and damped down by feelings of self-reproach, inadequacy and depression (Truelove (1965)). The paradox of hypermotility with constipation and hypomotility with diarrhoea has been highlighted by Connel et al (1962).

Hirschsprung's Disease

It has been proved repeatedly that the integrity of the myenteric plexus is the essential requirement for normal functioning of the colon. The absence of ganglion cells in this area means that there are no post-ganglionic fibres and, as a result, the smooth muscle cells react to the acetyl choline liberated by the pre-ganglionic fibres by contracting vigorously. This causes spasm of the bowel segment, instead of co-ordinated movement.

Aldridge and Campbell (1968) state that 13 years after von Hirschsprung's description of the disease in 1888, Tittel recorded aganglionosis of the distal segment. In 1948 Whitehouse and Kernohan described their findings in eleven cases of megacolon due to Hirschsprung's and in 1949 Bodian, Stephens and Ward compared aganglionic with normal bowel. These three authors elaborated on this in 1950 and 1951.

Aldridge and Campbell (1968) suggest that rectal suction biopsies in infants should be taken 2 cm. and in older children 3 cm. above the anal valves. This material must be fixed in formalin and serially sectioned as random sections are inadequate. Campbell and Noblett (1969) have since designed a rectal suction biopsy tube of great

/precision ....

precision.
Swenson and Bill (1964) were among the first to remove the aganglionic segment by a 'pull through' operation and so opened up a new field in paediatric surgery.
Should a major contribution to the enteric ganglia follow the cranio-caudal pattern this could account for the fact that Hirschsprung's disease involves more distal segments of bowel usually. However, it does not account for 'skip lesions', if these occur, and a dual origin seems on balance likely to be proved correct.
Hukuhara quoted by Truelove (1965), has shown that depriving a segment of colon of its oxygen supply for four hours results in death of intramural ganglion cells with resultant tonic contraction of the gut. They suggested this as a possible mechanism for the production of Hirschsprung's. Lister quoted by Vanhoutte (1969) observed vascular abnormalities in three out of ten cases of histologically proven Hirschsprung's disease. Could these be considered as occurrences insufficient to produce even the Grade 1 type of atresia proved to be caused by vascular insufficiency by Louw et al (1959)?
According to the findings of De Villiers (1966) this thesis is open to considerable doubt.

The brunt of the insult is borne by the subserosal and submucous vascular plexuses of Michels et al (1965) in the first instance. Then, as the submucosal plexus forms a highly anastomotic network, it recovers well and the adjacent mucosa regenerates completely. The subserosal plexus however, made up of fine branches in the first place and receiving minimal anastomotic supply,makes inadequate recovery, and the tissue it supplies tend to become replaced by scar tissue and form atretic lesions. These vascular plexuses are described in Part 6.

Ano-Rectal Malformations

The fact that the myenteric plexus still functions when the sub-mucosal one is removed has relevance to 'high' anomalies, in whom the blind pouch of mucosa and submucosa is cored out in the Rehbein/ Soave/Nixon/Kiesewetter operation.

b) Nerve endings in the Ano Rectum

i) Autonomic. Noberg quoted by Truelove (1966) found sympathetic

/fibres ....

fibres ending in close association with parasympathetic ganglion cells suggesting that 'adrenergic inhibition of intestinal motility is mediated by an effect on the post ganglionic parasympathetic ganglion cells'. This might account for some of the anomalies pointed out by Gillespie (1961, 1962).

Post-ganglionic parasympathetic fibres, viewed under the electron microscope, probably form discrete neuro-muscular junctions in the opinion of Kuntz quoted by Truelove (1966).

ii) Somatic. Duthie and Gairns (1960) gave a full description of the sensory innervation of the anal canal.

Somatic fibres from the inferior haemorrhoidal nerve supply the canal. The skin below the pecten has ordinary cutaneous sensation and the same nerve endings as the rest of the skin.

The Pecten Free nerve endings and organised endings, capsulated and unencapsulated, are present. Some of the organised endings can be placed in known categories, whereas others are unique to this situation. (Photo 4.19 shows one such entity, a 'loosely coiled' unencapsulated ending in the sub-mucosa of the five month old infant.) This corresponds with the findings of Kadanoff and Cuckov (1965) who found this zone to contain two thirds of the receptors of the anal canal. They however, found no true Golgi-Mazzoni endings. Heat and cold are felt more acutely in the anal canal than in the surrounding skin.

Crypts and Valves. More free nerve endings, which may have the role of distinguishing between solids, liquids and gases are found in this region, whose innervation otherwise resemble the pecten. Kadanoff and Cuckov found slightly more than a quarter of their receptors in this region.

Above the Valves. Touch can be appreciated up to a maximum of 0.75 cm. and pin-prick, which is acutely felt below the valves, more even than by the skin, is felt to a maximum of 1.5 cm. above the valves.

We found a tremendous wealth of nerves in this region including many which resembled those depicted by Duthie and Gairns (1960). Both thick and thin axons were noted and some fibres extended to

/within ....

within a cell's breadth of the lumen. Photo 4.20 illustrates some fine ramifying fibres in the submucosa. Focal depth makes it difficult to show the enormous number of nerves found in this area. Photo 4.21 shows autonomic fibres forming a plexus round a bloodvessel in this region. With care numerous tiny cross connections can be traced.

2) Bladder and Urethra

a) Ganglia

Blanca Smith (1968) describes the development of autonomic ganglion cells in the adventitia and between the muscle layers with some placed in the submucosa. Her findings are essentially in agreement with those of Leibowitz & Bodian (1963) as ganglia are found by both workers to be maximally concentrated at the base of the bladder and related to the terminal ureters. Most are found in the adventitia, then in the outer third of the muscular coat and only a few are in the submucosa. Their number decreases between base and fundus and from base to anterior midline. Very few ganglia are found in these positions. These ganglia arise according to Yntema and Hammond (1953) in common with abdominal and pelvic ganglia from neural crest/or tube of the trunk region.
Ganglia are noted by Krantz (1951) to lie along the lateral margins of the urethra and vagina and to send twigs between them, as well as, to them.

Up to the third prenatal month vesical and enteric ganglia develop pari passu but from the fourth month a drastic change in the morphology of the vesical neurones occurs and their maturation rapidly outstrips that of the enteric ones. This finding Smith (1968) believes may be correlated with the onset of the elimination of urine during the fourth-fifth month of foetal life.

b) Nerve endings

Sensory endings can be found in every one of the four layers of the vesical wall and are clearly described and illustrated by Kuru (1965). Encapsulated and non encapsulated endings of simple and complex variety are found.

/Weddell's ....

Weddell's assumption (1961) that most encapsulated endings do not differ as much in function as in appearance is supported by the following findings quoted by Kuru -

i) Complex and simple encapsulated endings may arise from a single fibre.

ii) The proportion of simple to complex forms is less in adult cats than in kittens. This corroborates Weddell's discovery that Meissner's corpuscles in the human conjunctiva are only present in adults and represent frustrated, worn out nerve endings which disappear after application of methylene blue.

iii) Single nerve fibres have been seen to give rise to five terminal filaments, three ending in Pacinian bodies and the other two making connections with loops and festoons of fibres and end bulbs.

A great similarity between nerve-endings in the bladder and those in the terminal bowel is apparent.

The mucosal lining is sensitive to touch and pain and Bors and Blinn (1957) have found iced water induces an acute desire to void.

In the muscle layers complexly ramifying Ruffini like terminals predominate. Tension receptors of two types are suggested:-

One is rapidly adapting and is excited by both

a) Rapid change in vesical content

b) Active contraction of the bladder

whereas the second, which adapts slowly, is stimulated briefly by rise of intravesical pressure.

It is of interest that action potentials can be recorded in the hypogastric, pelvic (nervi erigentes) and pudendal nerves when the urethra is distended, but flow of saline through the urethra only gives rise to these in the pudendal nerve (Kuru, (1965)).

Photo 22 is of the transversely sectioned five month female foetus. Below is the pouch of Douglas. To the left is the cervix. Above is the smooth muscle of the bladder wall. Centrally nerves and clusters of ganglion cells can be seen. Radiating from one of the ganglia towards the cervix and bladder wall three distinct sets of

/branches ....

branches can be located in the high power view shown in Photo 4.23.

c) Collation

The bladder functions as a compliant reservoir for urine, which from time to time empties itself completely. In reflex micturition bladder distension is the most important initiator of vesical contraction; on the other hand the sustained contraction of the detrusor necessary for complete emptying depends on tension receptors which are excited by contraction of the detrusor itself. Because in paraplegics with damaged sacral cords and sensory changes the reflex vesical contraction, which can be elicited by distension as well as by iced water, is abolished, some of the vesical afferents related to these reflexes are concluded to be in the mucous and submucous layers of the bladder (Bors and Blinn, (1957)).

Gross degeneration of vesical ganglia and their replacement by fibrous tissue was found by Smith (1968) to follow recurrent infections of the urinary tract and might account for the dilatation of the bladder neck and urethra recorded by Krooigard (1967) although Eckstein (1967) considered the larger urethral lumen normal in childhood before the vagina develops a thicker wall.

Leibowitz and Bodian (1963) of course proved that there is no evidence of the mega-ureter megacystis syndrome being akin to Hirschsprung's disease, which supports the evidence for different origins of the ganglia of bowel and bladder.

Bors and Blinn (1957) found that when local anaesthetics were applied to the bladder mucosa the resting electromyograph of the pelvic floor muscles is greatly reduced - this is especially so in the recording from the external anal sphincter. They have shown by this manoeuvre as well as by:

a) squeezing glans
b) pulling on urethral catheter
c) pulling on a suprapubic catheter

which also result in external anal sphincter contraction, that a mucosa to pelvic floor reflex is operative in addition to the mucosa to detrusor invoked by iced water in the bladder.
This reflex is useful in paraplegics with an automatic (above S3)

/type ....

type of cord bladder. These will be correlated with other reflexes in Section V.

Boyce et al (1964) experimenting with electronic implants in the detrusor, which can increase intravesical pressure, found that, in order to avoid patient discomfort due to stimulation of adjacent somatic nerves or sensory endings, they had to place the implants in each lateral bladder wall. In the trigone, where maximal ganglion concentration is, irradiation would be greatest. It is interesting that they found implants in the dome least successful, doubtless because as Liebowitz & Bodian (1963) and Smith (1968) showed, the least number of ganglion cells are located here.

Scott et al (1965-1966) performed investigations to find out whether stimulation of trigger points, or stimulation of multiple points, on the bladder, were required to produce effective bladder emptying. In dogs, their findings were in accordance with anatomical findings - in the dome there was nil response, on the anterior-inferior surface a slight response was obtained, and between the uretero-vesical junctions excellent voiding with complete emptying took place

In one paraplegic patient they found the larger the number of electrodes the better the response and they suggested that perhaps the trigger area is even more precisely placed in man.

A large number of electrodes increased associated abdominal and perineal muscular contraction. The abdominal contraction must be on the basis of the findings of Downman et al (1955) who ascertained that stimulating the viscera in spinal and decebrate cats provoked reflex contraction of skeletal muscles. Stimuli employed were single shocks, digital pressure, heating and application of salt solutions. Tonic and plasic movements of limbs, especially the hind limb, as well as of abdominal and pelvic muscles, sometimes occurred as well.

Such implants if they can be perfected might solve the problem of re-education of the bladder in the paraplegic as Guttman (1959), amongst many others, has shown this to be much less satisfactory than that of the bowel.

3) Uterus and Vagina

Perhaps because of their vital role in the perpetuation of most mammals the uterus and vagina can operate efficiently when all extrinsic nerves to them are divided. The endocrine system has been believed to be the main regulator of myometrial activity.

However, as Gruber (1933) quotes Vesalius in 1559 describing an autonomic nerve supply to the uterus it seems worthwhile to consider some recent work on autonomic fibres and ganglia, which are present in such abundance and can be seen to enter certain parts of the female reproductive tract.

Ivy (1942) notes 'pacemaker' activity in uterine muscle spreading from the insertion of the uterine tubes in the Rhesus monkey. Waves which begin bilaterally and synchronously spread from these areas. As the waves approach the midline the body of the uterus is seen to shorten longitudinally and a circular contraction appears at the level of attachment of the round ligaments (this must be the upper attachment.) This circular wave moves caudalward over the lower segment and finally involves the cervix. The musculature over the placental site is less involved in contraction than the remainder of the uterus. The arrangement of muscle fasciculi in the uterus described by Goertter, quoted by Ivy(1942), shows two interlacing spiral systems which can be traced to the unfused Mullerian ducts. Their disposition corresponds well with the mode of travel of the wave of contraction in the monkey uterus.

Sympathetic Innervation

Owman et al (1967) have, in fluorescent studies, demonstrated adrenergic fibres passing, not only to the blood vessels, but also to end in relation to the smooth muscle of the tubes, uterus and vagina and in the parenchyma of the ovaries. There was a special concentration of nerve endings in the circular muscle layer of the isthmus of the tube and the number of adrenergic endings was found to be three times as high in the cervix as in the uterus which must surely be linked with the importance of this region in parturition. Has the tubal concentration any relationship to the pain sensitivity of this organ remarked by Jeffcoate (1969)?

They further remarked that the organisation of the sympathetic

/innervation ....

innervation of the reproductive tract is perhaps unique in that post-ganglionic fibres originate, not only from pre and paravertebral ganglia, but also from adrenergic ganglionic formations located in the immediate vicinity of the effector organs. This latter type of short adrenergic neurone, they state, differs functionally from the ordinary long one although they do not say how. As at other peripheral adrenergic endings nor-adrenaline is the major catecholamine secreted. Adrenaline if present accounts for less than 5% of the catecholamines of the female reproductive tract.

Photo 4.24 shows an impressive collection of ganglion cells and nerves in the angle between the vagina and rectum which are close to the utero-vaginal junction in the same specimen as Photo 2.15 etc. Above is part of the vaginal wall, below is the bowel. To the right is the levator bypassing the perineal body. Note the great thickness of the longitudinal coat of the bowel in this new-born infant and the break in the inner circular coat anteriorly.

Parasympathetic Innervation

Painstaking and technically exacting experiments by Greiss et al (1967) have proved that direct parasympathetic nerve stimulation sufficient to evoke marked bladder and rectal contractions, produced

a) no change in the uterine vascular bed of pregnant and non-pregnant ewes, which others have claimed is increased by such a manoeuvre, and,

b) no significant effect on myometrial contractility.

The purpose of the parasympathetic ganglia in the isthmus and cervix and in the broad ligament adjacent to the body of the uterus is thus unexplained.

The same workers (1967) found that intra-arterial injection of acetyl-choline induced marked vasodilation in the uterine vascular bed of the ewe. They pointed out a relationship between oestrogens, acetyl-choline and uterine vasodilation whereby the effects of acetyl-choline varied depending on the oestrus cycle in the non-pregnant, and was minimal in the last two trimesters in pregnant, animals.

They believed that, as nerves are not causing the release of acetyl-choline, this substance is produced in a non-nervous tissue source

/such ....

such as has been proved to occur in the nerve free placenta which has the highest concentration of acetyl-choline of all tissues tested.

Photo 4.25 shows numerous nerve fibres within the vaginal wall as well as outside it. The lumen is above and the pale areas are all nerve fibres.

Is some imbalance of autonomic control, as Jeffcoate (1952) suggests, responsible for the fact that about 50% of all women experience some alteration of bowel habit related to menstruation? Pre-menstrual constipation and slight looseness of bowels with onset of flow - either one, or both, occur. Exacerbations of the 'irritable colon' syndrome in women nearly always coincides with menstruation.

PART 6.

ANO-RECTUM: CORRELATIVE ANATOMY

Nature can never be sufficiently praised for having lavished upon the end of the intestinum rectum, muscles which speedily retract for the purpose of excreting faeces which have pushed into the rectum; and in addition she has provided another muscle which prevents the untimely or involuntary expulsion of excrement.

Vesalius (1543)
Translated by I.A. Beck.

A. MORPHOLOGY

Fowler's (1963) chapter on the landmarks and legends of the anal canal is itself a conclusive landmark, leaving little to be said on the anatomy of the anal canal. According to his definition the surgical anal canal begins at the level of the ano-rectal ring above and ends at the anal intermuscular depression, between the lowest part of the internal sphincter and the external sphincter below, both easily palpable entities.

Harkins (1965) adds little to what is now generally accepted and draws attention to certain inaccuracies of surgical anatomy which have now been largely corrected. The first inaccuracy pertains to the relative positions of internal and external sphincters now fully appreciated since Eisenhammer (1951) inadvertently pointed out the true nature of the 'pecten band' when describing internal sphincterotomy for chronic fissures and other stenotic conditions of the sphincter.

Secondly he suggests further investigation of Eisenhammer's (1958) claim for anal glands as 95% of the source of infection is fistulae.

Thirdly he points out the odd relation of urethra to rectum in Naunton Morgan's (1949) article which I also noted. The fourth point has been highlighted by many authors and is that most cases of ano-rectal malformations are associated with fistulae.

a) Layers

From within out the layers of the anal canal and lower rectum are:

i) Mucosa which lines the features of this region, viz. pecten, valves, crypts and anal columns and becomes continuous above with the rectal mucosa. Walls (1958) (1969) has most expertly sorted out

/the ....

the complex histology of the areas between the rectal mucosa and the glabrous anal verge in the adult.

According to this histologist:

A) Proximal 4-16 mm is lined by typical columnar rectal mucosa showing tubular intestinal glands

B) Between the point at which rectal type mucosa ends and the line of the anal valves, there is a zone 1-9 mm. long which varies with regard to its epithelium. In some there is stratified squamous, in others stratified columnar and in yet others interdigitation of stratified squamous and intestinal epithelium occurs.

C) The crypts are lined by stratified columnar cells, which give a positive reaction for mucus, and here mucosa is firmly adherent to submucosa as glands pass outwards.

D) Anal valves and the line of approximation of internal and external sphincters, including the pecten, is 8-15 mm. in length and is lined by stratified squamous epithelium.

Within the lower regions an occasional sebaceous or sweat gland and rudimentary hair follicles show it to be modified skin. Keratinisation and melanin in decreasing amounts may extend up to the valves and Duthie and Gairns (1960) found Keratin and pigment cells ending just above the valves which might be an important factor in considering the sites of tumours.

E) Change from pecten to peri-anal skin is marked by the appearance of hairs, sebaceous and sweat glands and the large apocrine glands so frequently the site of hydradenitis suppurativa.

Walls (1958) avoids the use of the term transitional for describing a change of epithelium from one type to another and considers the appearance, recorded by others of epithelium resembling bladder mucosa, as due to technical difficulties. His meticulous studies seem fully to illumine the subject.

ii) Submucosa

Here are found the well known venous plexus, arterial twigs, nerve fibres and ganglia and the 'sustentator tunicae mucosae' of Kohlrausch now termed 'musculus submucosae ani' following the

/researches ....

researches of Fine and Lawes (1940), who still believed it to be part of Miles 'pecten band'. This extends down as a thickened portion of the muscularis mucosae of the rectum through the entire length of the ano-rectum. It is regularly seen during haemorrhoidectomy and has been carefully described by Stonesifer among others(1960). He and Walls (1963) differ from Fowler (1963) in denying that conjoined coat-tails join this layer by traversing the internal sphincter. Photo 4.26 indicates the width of the muscularis mucosae in the rectum of an elderly adult male. In Photo 4.27 the increase in width of this layer, which is now the musculus submucosae ani, is apparent even although this is a medium power view. The photo is of the same specimen.

The function of musculus submucosae ani may be to prevent prolapse of mucosa after defaecation and to help with the sealing of the anal canal lumen referred to in Section V.

It seems likely that Brossy (1959), Fowler (1963) and Stonesifer (1960) are right in considering that Parks' mucosal suspensory ligament described again in 1969, is simply a part of this elastic coat.

Projecting from the crypts, and in some places penetrating the internal sphincter, are the anal intermuscular glands, 8-10 or so in number, lined by cuboidal epithelium. Wax models of these glands were made by F. Paradise Johnson (1914) which give one a clear concept of their dimensions.

Parks (1969, 1961) believes that infection of the anal glands is the cause of two thirds of all fistulae-in-ano. He claims that Chiari first described them in 1878 and suggested them as a cause of fistula at that time. He does not mention Eisenhammer (1958), who is more generally accredited with noting the glands as a source of infection. Parks' diagrams of the pubo-rectalis in these articles are very difficult to interpret. His contribution has been to point out the planes along which infection might track although Fowler also drew attention to such planes.

iii) Internal Sphincter

The internal sphincter labelled as the subcutaneous external sphincter is shown in Fig. 8 of an article by Milligan et al (1937).

/Credit ....

Credit for recognising that the sphincter identified during haemorrhoidectomy operations was the internal and not the subcutaneous external sphincter goes to Goligher et al (1955-6) and was also noted by Naunton Morgan and Thompson in 1956. The internal sphincter has been shown by Schuster (1965) to make a major contribution to elevation of pressure in the sphincteric zone as proved by the diminution in pressure which follows sphincterotomy. This thickening of the lowest part of the circular muscle coat, which has a vertical extent of 25-30 mm. and is 2-5 mm. at its widest, forms a part of the ano-rectal ring, and, inferiorly extends below the dentate/pectinate line and is separated from the external sphincter by the anal intermuscular depression. It is divided into coarse bundles which are traversed by a few medially directed coat-tails and, at the level of the valves and crypts, by some anal intermuscular glands. It is shown in Plate 4.7.

It relaxes in response to rectal distension and so allows faecal material to be sampled by the mucosa, rich in nerve endings at the ano-rectal ring, as shown by Duthie (1960).

Its function is to contribute to the ano-rectal ring and, with other factors, to form an air and water tight seal.

An interval in which ganglia, nerve fibres, bloodvessels and a quantity of connective tissue, especially disposed longitudinally, separates the internal circular muscle coat from the conjoined longitudinal one.

iv) Conjoined Longitudinal coat

Formed, as we have seen, by fascial and muscular accessions from the levator and its fascia, the fascia of Treitz and the fascia of Waldeyer joining the tela subserosa, this consists of intermingled longitudinally disposed muscular and fibrous elements which, about halfway between the ano-rectal ring and the dentate line, as first noted in 1858 by Beraud, fans out into septa which break up the external sphincter as previously described. In adults these 'coat-tails' are mainly fibro-elastic and in children some are still composed partly of smooth muscle. Those fibres which pass medially, as noted by Fowler, join the musculus submucosae ani, from which in turn, they may rejoin the conjoined coat. The importance of these strands in the spread of infection is

/stressed ....

stressed by Fowler and Morgan and Thompson (1956) amongst others. Wilde (1948) gives a fine historical review of this layer and notes that Roux in 1881 compared the coat-tails to the whiskers of a paint-brush and that Laimer (1884) believed that the levator by this route sent some fibres to blend with the circular coat where they terminated in the substance of the internal sphincter - an 'impression' similar to that gained by Lawson (1967). Wilde calls it the anal 'intra-muscular septum' which I think is a highly misleading name.

Plate 2.50 shows the general disposition of the conjoined coat and its 'tails' and Photo 2.51 shows them passing through the external sphincter. In Photo 2.51, which is of the five month-old foetus at the level of the superficial external sphincter, part of the lumen of the bowel is to the right, the inner circular and some longitudinal bundles can be distinguished. Traversing the striated muscle 'coat-tails' of smooth muscle and collagen are clearly apparent.

P.H. Lord (1969) has a theory that haemorrhoids are due to a narrowing of the lower rectum and/or anal canal, which interferes with the normal process of defaecation and leads to an abnormal raising of intrarectal pressure during the act causing venous congestion. He therefore treats them by dilatation of the ano-rectum. Initially, dilatation of alarming magnitude is performed under anaesthesia by the surgeon, and later the patient, using an appliance, goes onto a scaled regime which includes normacol medication and lasts for six months. If in fact such stretching does prove to be beneficial an anatomical basis for the procedure must be:

a) Excessive anchoring of the ano-rectal junction which is easy to envisage

b) The conjoined coat-tails, which pass through the internal sphincter into the submucosa, may hypertrophy and strangle the veins in the plexus. Breaking of these strands might produce amelioration.

After this drastic procedure sphincter exercises may be necessary for two to three weeks post-operatively but full continence is apparently always restored eventually.

It is noteworthy that dilatations (with four fingers not eight) after

/haemorrhoidectomy ....

harmorrhoidectomy, by any method, did not reduce post-operative pain in a statistically significant fashion when stringent criteria were applied to the enquiry although, the number of patients in whom pain was reduced, encouraged Goligher (1966) to include gradual stretching as a routine preliminary to these operations.

The ano-rectal ring is formed by the sling complex (pubo-recto-analis and deep external sphincter) and the upper part of the internal sphincter with, between them, a part of the conjoined longitudinal coat.

Walls (1969) states that the ano-rectal ring is composed 'posteriorly and laterally by the pubo-rectales, anteriorly by the deep fibres of the external sphincter'. The rest of his definition though vague is acceptable. This statement is made in a book designed for tutorials at a post-graduate level.

The closely integrated unit of the ano-rectum and the position and direction of the terminal bowel are repeatedly illustrated.
I have consistently found the very irregular pectinate/dentate line, formed by the anal valves and crypts, at a lower level than shown in Fowler's diagram and more in accord with earlier works, e.g. Johnson (1914), and very recent ones, e.g. Kelly (1969), but it seems always to be above the lowest level of the internal sphincter.

Outside the anal canal, but by virtue of 'coat-tails' firmly tethered to its walls, we find the divisions of the external sphincter already described, with the 'sling complex' and wandering levator strands binding the external anal sphincter and levator to each other.

b) Elastic tissue

In the submucosa and related to the muscle coat, as shown in Photo 4.28, elastic tissue is found to be abundant. Some is related to conjoined coat-tails, some to bloodvessels and the rest appears disposed in a non-specific manner. Its function would appear to be to improve the resilience and resistance of this region thus helping to keep the lumen closed for long periods of time. Jackson and Robertson (1965) note a definite decrease in elastic tissue in the submucosa with an increase in collagen fibres in the elderly and in patients with haemorrhoids.
Their quoted comment that the lack of haemorrhoids in quadrupeds can be

/attributed ....

attributed to the fact that they do not strain on defaecation is true of ungulates, but not of carnivores.

c) Blood Supply

The vessels supplying the ano-rectum are:-

1) Superior rectal
2) Middle rectal
3) Median sacral
4) Inferior rectal
5) The blood vessels which supply the levator furnish twigs to the bowel wall
6) Other visceral branches of the internal iliac, notably the inferior vesical and vaginal arteries, have small offsets which reach the bowel.

The superior rectal vessels are well documented and their position has been noted in relation to fascial layers and autonomic nerves. Michels et al (1965) in a mammoth survey of the literature and dissection of 400 specimens found that:-

1) In 81% the artery bifurcates the R branch often being longer.
2) In 13% it trifurcated into branches of equal size.
3) In 4% it divides into more than three branches.
4) In 2% it coursed in midline on posterior wall forming anastomotic loops on both right and left. I have not seen this variant.

The larger R. branch divides into several branches, which descent vertically or obliquely on the posterior and lateral aspect of the ampulla. The smaller left branch, deviates in angular fashion to the left border, which it circumflexes, to supply the lateral and anterior aspect of the rectal ampulla.

These branches do not form arcades, but, as they decend enter the gut wall directly and independently. Their observations on entry points of the vasa recta prove conclusively that the vasa recta in the colon enter the gut wall at a point further away from the mesenteric border than they do in the small intestine.

They have traced the vasa recta into the lamina propria where their fine branches form plexuses, these the authors term subserosal, but this name can clearly not obtain below the peritoneal reflection. From here several large

/branches ....

branches pass directly to the submucosa to form a prominent and highly anastomotic submucosal plexus which must be related to Meissner's nerve plexus. It is from here that the terminal vasculature of the bowel wall is derived. Two sets of vessels leave the submucosa, one passing outwards to form a finely interwoven network of arterioles, which lies between the longitudinal and circular muscle coat, and must thus be closely related to Auerbach's (Myenteric) plexus of nerves. The second passes inwards and terminates in a fine subepithelial network which constitutes the mucosal plexus.

The complicated intramural plexuses have the same form in relation to all three sets of rectal arteries.

Prominent venous channels are found in the submucosa and also form a significant plexus in the lamina propria. It would be interesting to know whether arterio-venous anastomoses abound in this region.

The superior rectal arteries are, without doubt, the major source of supply of the rectum and ano-rectal region.

The middle rectal arteries are also analysed by Michels et al - They note that the vessels are seldom symmetrical in origin, length, width course or number, up to three branches in some cases.

They found the vessels to arise most commonly from the internal iliac and to often arise from parietal branches thereof, whereas Boxall et al (1963), whose other findings in respect of this vessel I can fully corroborate, found, as we did, that their origin is usually from visceral branches of the internal iliac especially the vaginal in the female and the genital (Uhlenhuth (1963)) or inferior vesical in the male.

It is closely related to the upper surface of the levator ani as shown in Fig. 1.7 and sends its main contribution onto the antero-lateral bowel wall after traversing the part of the recto-vesical/vaginal septum which joint Waldeyer's layer of fascia. This is sometimes called the 'lateral ligament' of the rectum. Further fine branches supply the fascial septum anteriorly and anastomose with superior rectal channels as shown in Fig 4.29 and pass to the posterior aspect of the bowel.

The median sacral artery is small and its potential does not appear great - moreover it is in a vulnerable position when the ano-rectum is mobilised.

The inferior rectal branch of the internal pudendal artery supplies the

/anal ....

anal canal after ramifying to supply the external anal sphincter in company with branches of the pudendal nerve and perineal branches of the fourth sacral nerves. It is reinforced by the transverse perineal branch of the perineal artery.

B, CO-ORDINATION OF ANO-RECTAL FUNCTIONS, NORMAL AND ABNORMAL, WITH THAT OF THE EXTERNAL ANAL SPHINCTER, SLING COMPLEX AND THE REST OF THE PELVIC FLOOR AS SHOWN BY SPECIAL TESTS.

The diagnosis of very many conditions of the ano-rectum and pelvic floor can be made with a careful history and clinical examination, including such refinements as sensory testing of the lining of the ano-rectum. However, in the last century techniques have been developed, which yield information obtainable in no other way. These have corroborated or negated clinical impressions, thus leading to greater accuracy in diagnosis and more valid assessment of the results of treatment. They are pressure studies, electromyography and radiology. Frequently a combination of the three refines diagnosis immeasurably. A short review of some aspects of these follows.

1) Pressure studies
2) Electromyography
3) Radiology.

1. Pressure studies

Denny Brown (1933), Gaston (1948, 1951), Goligher and Hughes (1951), Hill et al (1960), Porter (1962), Schuster (1963, 1965) and Duthie (1965) in adults, and Schapiro (1948) and Nixon et al (1964) in infants are among those who have recorded pressure traces from the ano-rectum. These give an indication of the compliant reservoir functions of the bowel, the resistance to the passage of balloons provided by the valves of Houston, and the zones of increased pressure in relation to the 'sling complex' and the external anal sphincter. Changes in sphincter pressure with alterations in rectal volume and intra-abdominal pressure can also be analysed, as can relationships between subjective symptoms and objective signs. The effect which slow and rapid rectal distension has on rectal contraction can also be assessed.

When the normal rectum is distended and slight discomfort is felt the

/internal ....

internal anal sphincter relaxes and the external one contracts vigorously.

Goligher and Hughes (1951), using digital manometry, noted that occasionally external sphincter contraction, induced by rectal distension, preceded the appreciation of a sensation by a second or two.
Schuster et al (1963) state that internal sphincter relaxation with rectal distension was first reported by Gowers in 1877. Unlike Gaston (1951) these workers found sigmoid distension also produced the reflex. The same workers (1963, 1965) found that when a balloon in the rectum was filled with about 150-200 ml. of air in an adult and a critical pressure of + 50 cm. H_2O was recorded (which corresponds to a volume of $1\frac{1}{2}$-3L in different subjects) there was inhibition of the external anal sphincter as well. (c.f. D.O.P.) All the pelvic floor muscles, except, I believe, the cranial levator fibres joining the conjoined coat, also relaxed. Evacuation tended then to ensue.

In four children between five and eleven years old Callaghan and Nixon (1964) found that there was a rise in pressure of 7 to 10 cm. H_2O for every 50 ml. increment.
Two points were noted:

a) the pressure at which continuous rectal sensation occurred

b) the pressure at which inhibition of the striated sphincter took place.

The latter is about 60-75 cm. H_2O with a volume of 100 - 150 ml.

The contribution of the internal sphincter to the band of elevated pressure which, in adults, extends 3-7 cm. (mean 4 cm.) cephalad of the anal margin and is highest in the upper portion, is believed by Schuster (1965) to be considerable. This judgment was based on the reduction in pressure which follows internal sphincterotomy, although the resting pressure is always above the ambient even after this operation. Normally raised pressure in the anal canal can be registered to within 0.5 - 1 cm. of the anal verge.

Harris et al (1966), using minute, open ended, water-filled polyvinyl catheters, showed that the anal canal pressure barrier is perfectly balanced to resist distension. Thus, with the tubes sited so that one was in the anal canal and one in the rectum, injecting minute increments of fluid into the latter produced stepwise pressure rises in the former until a plateau was reached. Thereafter withdrawal of these minute quantities was recorded as a stepwise decrease in pressure of the sphincter. The plateau level

/they ....

they called the 'resting yield pressure' and found it to vary between 60-100 mm. Hg.
Tightening of the sphincter, when the plateau was reached, led to a further stepwise increase with increments, which again reached a plateau. This they termed the 'augmented yield pressure', and this was found to be between 200 - 260 mm. and in some reached 300 mm. This agrees very well with the findings of Agostoni and Rahn (1960), who found that intra-abdominal pressure can rise to 280 cm. H_2O with maximal expulsive efforts and also with those of Campbell and Green (1953). Both 'resting yield' and 'augmented yield pressure' are greatly reduced in incontinent subjects.
Schnauffer et al (1967) showed conclusively that the external sphincter is of extreme importance in continence because one case with a high, and one with a low ano-rectal anomaly, was continent, post-operatively, despite absence of internal sphincter relaxation.
I am sure that the 'sling complex' and perhaps, some medially placed levator fibres, also play a vital part in this phenomenon.

This work shows the delicately balanced feed-back circuits operative between the rectum and anal canal and the pelvic floor via the sacral cord and brain stem. It is likely that receptors in the muscles surrounding the ano-rectum are involved directly in these adjustments.

Pathology

Porter (1961) found that with abnormal rectal function changes might be found:

a) in the pattern of the rectal pressure graph
b) in the threshold for subjective rectal sensation
c) in the threshold for reflex sphincter inhibition.

In Hirschsprung's all these parameters were normal, but see later. In cases with megarectum and normal colon, a very high threshold for sphincteric inhibition was present, and in megarectum with megacolon, rectal sensation was absent and the inhibitory threshold was enormously raised.

In relation to megarectum in children Callaghan and Nixon (1964) distinguished three groups, which they termed

1) Enlarged rectum which corresponded to Hurst's dyschezia with a raised threshold for inhibition but otherwise normal responses,
2) Expanded rectum which required a loading volume before any rise

/of ....

of rectal pressure occurred. Reflex responses were diminished and the pressure/volume gradient was frequently low.

3) Inert rectum had a low pressure/volume gradient < 5 cm. H_2O/50 ml. increment and had altered responses. Sphincteric inhibition occurred before rectal sensation arose.

The advantages of early treatment of low anal anomalies to avoid the development of rectal inertia were stressed (Nixon and Callaghan, (1964)).

2. Electromyography

a) Striated Muscle

This, coupled with pressure studies, has proved of the greatest value in analysing the various reflexes which obtain between the elements of the pelvic floor, perineum and viscera and in detecting dysfunction of striated muscle.

Correlation with the recordings obtained with pressure studies has been high.

Floyd and Walls (1953), Porter (1962), Taverner and Smiddy (1959) are some of the workers who have made real contributions in this field in adults.

The continuous activity of the pelvic floor muscles, except during expulsive efforts, or when contents are in transit, has been noted and so has the inhibition produced by unproductive or prolonged bearing down. Of especial interest is the fact that in amplitude and duration the action potentials of the pelvic floor muscles (external anal sphincter especially) resemble those of facial muscles, e.g. orbicularis oculi- another sphincteric muscle, being much smaller than those of other skeletal muscles - smaller for example than soleus. The PATTERN of discharge, however, differs widely from anatomically similar muscles and much more resembles that of soleus - a typical anti-gravity muscle.

The increased electrical activity associated with all rises in intra-abdominal pressure due to abdominal compression, vocalisation, laughing, sneezing, coughing, vomiting, straining, weight lifting etc. have been graphically demonstrated by Walls et al (1953), Porter (1962), and Taverner and Smiddy (1959). The vigorous 'closing' reflex of Porter follows expulsive efforts and has been repeatedly

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recorded.

Voluntary contraction of the external anal sphincter produces a marked increase in its electrical activity. This direct cortical effect can be sustained, at best, for only a minute, despite the fact that the subject is unaware that his contraction is not sustained for longer. Porter (1962), Taverner and Smiddy (1959), and Duthie (1963) have shown that this time is sufficient to allow the rectum to adapt to its increased load by its compliance, so that the danger of untimely expulsion has passed by the time that voluntary contraction fades.

I have not had time to digest the work of Kerreman's (1969, which arrived for review as I was completing my thesis. He has put an enormous amount of information into his book and his electrical studies are of a very searching nature. In general he confirms the findings of other workers although he was unable to show the effect of respiration on pubo-recto-analis which Taverner and Smiddy (1955) recorded. Amongst many items of note is the decreased activity recorded from the anterior and posterior commissures compared with that from the lateral bulk of the external sphincter. Slow waves, recorded from the external sphincter, comparable to those arising in smooth muscle may be due to electrodes in the conjoined coat or to smooth muscle admixed with striated. This is a most exciting finding as I shall elaborate on in Section V.

He noted electrical rest in occasional adults and infants but it was always of a temporary nature. In infants the degree of activity (i.e. pattern) and frequency is slightly higher than in adults. He finds that with maximal voluntary contraction, except initially, no fixed relationship between striated sphincter activity and anal pressure exist, but, the duration of E.M.G. activity, exceeds the duration of the pressure increase.

Although substantially I agree with most of his conclusions, I cannot accept his view that the tonic activity of the pelvic floor musculature is due to postural or antigravity activity. If this was so then the activity would disappear when lying down, during sleep and under anaesthetics. Furthermore in infants, in whom vigorous activity is recorded, the need for antigravity control is absent. This tone I believe is maintaining

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the form of the anal canal and the ano-rectal angle and in women is of importance in restoring the status quo after parturition.

b) Smooth muscle

Recordings from the smooth muscle of the anal canal have been recorded recently by Wankling et al (1968) and Kerremans (1968, 1969).

The presence of slow waves of a mean frequency of 20/min were noted by Kerremans and he postulated a 'cephalad directed vector force' which might I think be analogous to the 'reversed pressure gradient' noted in the rectum towards the sigmoid.

He concluded that his results strongly supported the participation, his wording was 'interference', of the internal anal sphincter in the venous reflux of the internal haemorrhoidal plexus.

Pathology - Adults

Diminished electrical activity in adults has been shown in Parks et al (1966) 'descending perineum syndrome', in which patients have a lax pelvic floor, vague aching and perineal pain and never feel that the bowel is empty. This leads to continued straining thus perpetuating the vicious cycle.

Reduced potentials are recorded from damaged muscles (Danielsson (1956)).

The value of electromyographic studies in children is illustrated by the following examples.

a) Schnauffer et al (1967) recommended pre-operative mapping of external anal sphincter fibres without an anaesthetic, in ano-rectal congenital anomalies so that 'pull-throughs' could be accurately placed. They have shown the importance of the external sphincter (sling complex) in continence in such cases as noted earlier.

b) In post-operative patients with a high anomaly, normal internal sphincter response to bowel distension occurred, which suggested to Schuster et al (1963) that sufficient thickening of smooth muscle fibres remained in the pouch, in these cases, to produce a reflex activity.

c) In subjects with Hirschsprung's disease Nixon and Lawson (1967) employed a specially designed probe, based on a balloon system developed from those of Denny Brown (1935), Gaston (1948) and Schuster (1965).

/Schnauffer ....

Schnauffer et al (1967) used a three balloon probe sited

a) in the rectum

b) related to the internal sphincter and

c) to the subcutaneous external sphincter.

Both types of probe were connected to a transducer and pressure changes were recorded simultaneously with electromyographic ones.

The first team used skin clip electrodes and the second placed circumferential needle electrodes in the external sphincter.

Both groups showed an abnormal response of the internal sphincter to distension. Nixon et al (1967) interpreted this as a continuation of the 'normal rhythmical contractions of the internal sphincter, which are in dynamic balance with low amplitude rectal contractions' and are not inhibited by the rectal distension of Hirschsprung's disease. Schnauffer et al (1967) state that internal sphincter 'contraction' occurs with rectal distension.

The lack of inhibition of the internal sphincter is definite in both these series and it contrasts with Porter's finding of normal sphincter inhibition in Hirschsprung's.

Kerremans (1969) suggested that dysfunction of the internal sphincter might be 'one of the possible pathogenetic factors of internal haemorrhoids.'

3. Radiology

Normal in Adults

i) Radiological studies of terminal bowel, coated with barium powder, were conducted by Phillips and Edwards (1965). These showed the anal canal to have its customary slit-like form and also that a zone of radio-translucency at the junction of the anal canal and rectum appears as the subject moves about. This segment, which is about 0.5 cm. long, appears to be emptied of powder by squeezing forces greater than those which impinge on the adjacent anal canal and they felt that it corresponded to the inner surface of the pelvic diaphragm. They further stated that it was too short to be explained by 'the squeeze of a muscle layer' but I cannot agree with this statement. It appears clear that this zone corresponds generally to the ano-rectal ring and

/is ....

is produced by the 'sling-complex' (pubo-recto-analis + deep external sphincter) mainly. It is satisfactory to note that the highest pressures in the anal canal are recorded from this very site. (See footnote). **

ii) The same investigators illustrated a faecogram in which radio-opaque faeces were passed. At first the anal canal was empty. As defaecation proceeded the pelvic floor descended and formed a funnel until the anal canal was opened and filled. With emptying the pelvic floor rose and the funnel was closed.

The virtual abolition of the ano-rectal angle during defaecation seems to be generally agreed on.

Faecograms combined with electromyographic studies, performed by Kerremans (1969) suggested to him that two definite groups of people, with different defaecation patterns, can be distinguished. As I understand him one group, about 20%, who responded immediately to the call to stool and are not trained for what he calls 'socially acceptable defaecation' have inhibition of E.M.G. activity on straining to defaecate-their sphincters relax with minimal distension of the rectum. On the other hand they cannot easily perform voluntary defaecation.

The other group, about 80%, those with a 'socially acceptable habit', who tend to put off a call to stool, respond to straining with increased E.M.G. activity of striated muscle during the initial phase or for the duration of the straining effort. They were able to evacuate voluntarily and kept their striated muscle contracted during a period of moulding of the stool and filling of the anal canal.

These investigations are of considerable interest but the issue certainly becomes confused if the pelvic floor, which has descended and is therefore presumably relaxed, shows increased electrical activity.

It may be that straining is one factor which introduces these discrepancies coupled with the artificial experimental set up which might easily lead to some voluntary contraction of the sphincter. On the

/other ....

** I find that Kerremans has also disagreed with Phillips and Edwards but his grounds for doing so are somewhat different from mine.

other hand Denny Brown (1935) remarked small relaxations of the external sphincter during defaecation, reciprocally related to rectal contractions. 'The jerky external sphincter continues irregular twitching throughout the relaxation. An occasional larger involuntary twitch of the perineum is superimposed.'

In infants

Faecograms performed by Cremin (1970) show features of the utmost interest because all the functions, which I had assigned to the various components of the pelvic floor related to the ano-rectum, on the basis of their attachments and position, can be seen in black and white to be valid.

Thus:

a) The ano-rectal angle straightens out almost completely with defaecation, as the 'sling complex', which indents the ano-rectum behind, relaxes.

b) The pelvic floor and perineum descend as many studies have shown, as most of the muscles relax (Kuru's reflex).

c) The anal canal SHORTENS to about two thirds of its length and this of course is what should happen if the cranial levator fibres, which join the conjoined longitudinal coat, are in fact active in defaecation, as I have postulated.
Further the canal, in a way which is analogous to the urethra, becomes SHORTER and WIDER, as I had anticipated, so that it can empty itself more completely.

d) A corollary of these changes is the partial obliteration of the valves of Houston as postulated in Part 1.

e) At the end of defaecation the ano-rectal angle is rapidly restored as the pelvic floor rises in the 'closing reflex' and the 'sling complex' and related musculature becomes vigilant again.

It is notable that Denny Brown (1935), whose writings often are very difficult to follow, also described brisk contraction at the end of defaecation.

Pathology

The role of X-rays in the diagnosis of ano-rectal disease would form the subject for a whole thesis so I shall only comment on a few

/landmarks ....

landmarks in radiology as they pertain to the field under discussion.

1. <u>In children</u>

Its use in the diagnosis of Hirschsprung's disease needs no comment.

<u>Ano-rectal Anomalies</u>

Numerous excellent radiographic studies of these conditions have been made since Wangensteen and Rice (1930) turned an infant upside down to measure the distance between gas shadow in the bowel and the anus, to which a coin or button was affixed.

Stephens devised an improved method depending on his pubo-coccygeal (P-C) line drawn from the middle of the pubic ossification centre to the lower border of the last (normal) sacral vertebra. This method yielded an excellent diagnostic aid as shown by the results obtained by Louw (1965).

Kelly (1969) uses great ingenuity in pin-pointing the margins of the cranial and caudal fibres of the levatores ani in the neonate in relation to a) pelvic viscera and b) easily identifiable points with reference to ossification centres. He has thus augmented Stephens P and C points with an I point which is the anterior-inferior extremity of the ischial ossification centre. This corresponds to the posterior limit of the ischio-pubic ramus near its superior border. On X-ray the wire threaded along the upper border of the levator seems to show a 'low' origin in all abnormal cases and in the normal male neonate. The outline shown in <u>Fig 2.</u> in the normal female neonate however, belies his description of the muscle as arising from the 'back of the pubis and along the white line of the obturator fascia as far as the ischial spine'. His observations on the musculature in relation to the valves coincides almost exactly with my findings and shows their superficial position in this age group as was shown in <u>Photo 4.4</u>. He has also described pubo-urethralis fibres looping round the urethra and pubo-vaginalis looping round the vagina; such loops can only very seldom be demonstrated.

Kelly's study indicates very clearly the great value of radiology in the diagnosis of ano-rectal malformations. He has reiterated the occasional fallacies that may occur due to descent of the levatores

/as ....

as a result of gas-filled bowel or raised intra-abdominal pressure which can lead to a false diagnosis of a 'low' anomaly. On the other hand contraction and elevation of the levatores can result in the erroneous conclusion that a 'high' anomaly is present. His 'supra' and 'translevator' nomenclature appears redundant.

Cremin (1970) has improved on the work of Kelly and has developed a scheme of parallel lines, drawn when the legs are well flexed, in relation to the pubis, ischium and sacrum, which allows extremely accurate definitions of 'high', 'intermediate' and 'low' anomalies.

2. In Adults

Rectal Prolapse

Fry et al (1966) produced outstanding illustrations of normal faecograms and of the position of the bowel and its behaviour in prolapse of the rectum which fully corroborate the findings discussed in Section V. Their di agram of the levator ani has a great deal to commend it but the external sphincter is proportionately too small and round instead of being boat-shaped. The absence of rectal wall fibres joining the perineal body and of Waldeyer's layer behind detract slightly from its value.

PART 7.

URETHRA AND BLADDER: CORRELATIVE ANATOMY

A. SELECTED TOPICS

a) Striated Muscle

It is fairly generally accepted that deficiency of striated muscle becomes manifest when additional strain is placed on it, as by a rise in intra-abdominal pressure, or, during movement. This is known as stress incontinence and as Ullery (1953) remarked, tends to develop

post-partum
post-menopausal
post-operative

Other factors besides muscular are involved as indicated in Section V. Elaborating slightly on these:

/Post-partum ,...

Post-partum cases may be due to direct trauma as shown by Petersen et al (1955) who in electromyographic studies of 13 multiparous women, found very slight or no activity in the posterior part of the urethral sphincter in all of them. They also found less activity posteriorly in nulliparous women, a point not stressed by Basmajian (1962). This is doubtless because the urethral body is here and lower down fibres join the vaginal wall. Thus it is mainly deep transverse perineal and bulbo-spongiosus activity, which is being recorded.

Kolan et al (1952) suggest that stress incontinence may develop when epistiotomy wounds are not sutured in the line of the muscle fibres. They contend that it is more common in subjects with a wide pubic arch - those with a narrow one being more prone to cystocele. This may be because the direction of the forces of labour in relation to the bladder depend on different pelvic conformations.

Post-menopausal cases may develop on a hormonal basis and will be referred to in Section V.

Post-operative cases may follow colporrhaphy and vaginal hysterectomy. Danielsson et al (1956) examined 12 patients after the Manchester operation (Shaw, 1949, 1954), eight of whom had some incontinence pre-operatively. They concluded that, due to scarring and nerve injury, defects in other parts of the external urethral sphincter were discernible in nine cases. They suggested excision and suture of scar tissue as a way of restoring normal function.

Greene (1962) has classified stress incontinence, which is a distressingly common complaint into two types. Type I, in whom there is complete loss of the posterior urethro-vesical angle only and Type II in whom, because there has been descent of the bladder and urethra, not only is the posterior urethro-vesical angle lost, but the normal 30° angle to the perpendicular becomes markedly increased. In many, urethral 'funnelling' is also notable. These changes are best shown by lateral cine-radiography. (Roberts, 1952 and Jeffcoate and Roberts, 1952).

In cases in whom the bladder neck becomes fixed by disease, especially carcinoma (Muellner (1949)) or, when spasm of the pelvic floor muscles develops after operative trauma, micturition may become difficult or impossible.

/Jeffcoate ....

Jeffcoate (1969) attributes deep perineal pain largely to spasm of striated perineal muscles after obstetrical injuries or surgical incisions. It is this spasm, which, by causing associated spasm of the external urethral sphincter, causes retention after perineorrhaphy. He believes trauma to vagina and urethra alone very rarely causes retention - it is muscle injury which is of such significance. Strangury is associated with referred pain in the pelvic floor in cases with severe vesical infection.

Well established in cases with automatic bladder and hypertonicity of the striated urogenital musculature is treatment aimed at reducing urethral resistance.

Pudendal neurectomy (bilateral) has its advocates, whereas others attack the muscles directly via a perineal approach or indirectly via the transurethral route. This has been practised with considerable relief by the Cape Town paraplegic unit (Retief, 1970).

b) Smooth muscle

Deficiency of the smooth muscle on the other hand, which may be due to nerve involvement, trauma or disease processes, manifests itself by incontinence at rest. It will be considered further in Section V.

Both striated and smooth muscle lesions, which develop on a neural basis, may lead to difficulties in voiding due to obstruction or incontinence or a mixture of the two.

c) Elastic Tissue

The importance of elastic tissue in the bladder neck and along the length of the urethra was highlighted by Pennington and Lund (1960). They found it to be a striking feature of the male urethra especially concentrated in a subepithelial collar at the junction of the membranous and prostatic portions thereof. They suggested that its removal, along with smooth muscle, might account for post-operative incontinence after transurethral or retropubic prostatectomy.

They accredited Elliot (1954) with this idea because he mentioned smooth muscle and 'connective tissue' removal as the cause of this incontinence.

Woodburne's name is more usually connected with stressing the

/importance ....

importance of elastic tissue, which he noted along the length of the urethra especially submucosally, but also intermingled with the innermost muscle fascicles (1969.

Our male material was disastrous but we were unimpressed with the elastic tissue shown in one newborn female urethra stained to show it.

Pennington and Lund (1960) noted scanty elastic tissue in the female urethra, compared with its abundance in the urogenital diaphragm in this sex. This feature was illustrated in Photo 2.67 and Photo 2.68. This is in contrast to its paucity in this situation in the male.

From the sections shown in the literature I am convinced that elastic tissue has a functional role in helping to occlude the male urethra. The pressure of elastic tissue and venous sinuses in the female urogenital diaphragm, I believe, add significant sealing elements to this structure.

d) Blood Supply of bladder and urethra

This is well described in most good textbooks. Krantz (1951) noted that all bloodvessels entered the bladder along its lateral margin, which is as it should be when one considers that the vessels are travelling in the umbilico-vesical (anterior) septum of fascia.

He also noted that the upper third of the urethra shared the blood supply of the bladder, whereas the lower two thirds received branches from the inferior vesical artery, whose branches also supply the vagina. An additional supply is furnished by the branches of the internal pudendal artery. These anastomose with superficial and deep external pudendal vessels.

/B. NOTES ....

B. NOTES ON BLADDER AND URETHRAL FUNCTIONS, NORMAL AND ABNORMAL, WITH THAT OF THE EXTERNAL URETHRAL SPHINCTER AND THE REST OF THE PELVIC FLOOR AS SHOWN BY SPECIAL TESTS

1. Pressure and Flow studies.
2. Electromyography
   a) Striated muscle
   b) Smooth muscle
3. Radiology - collation of radiology with normal anatomy seemed to fall more naturally into Section 2.

Pressure and Flow Studies

As stated earlier the normal bladder has a compliant reservoir function and an emptying function, which is carried through to completion.

Intravesical pressure, which is the sum of pressure due to detrusor contraction and pressure from outside (i.e. intra-abdominal), is pitted against urethral resistance.

Denny-Brown (1935) quotes Mosso and Pellacani in 1882 as studying pressure changes associated with gradual filling of the bladder. Resting pressure in the bladder does not normally exceed 10 cm. of H_20 even when the bladder is confortably filled. The bladder, under extreme stress, can exhibit a pressure of 100 - 120 cm. of H_20 (Jeffcoate and Roberts (1952)). Despite this, continence is normally maintained - the whole urethra remains closed and the posterior urethro-vesical angle is preserved.

Rankin has described a critical Detrusor Opening Pressure (D.O.P.) at which flow commences. This can be calculated by subtracting the measured rectal pressure from the total intravesical pressure at the moment when micturition begins. Increase in this pressure affords a sensitive measure of the degree of obstruction at the bladder neck from any cause.

Further, because of the difficulties inherent in measuring urethral resistance, the same worker has calculated, from the total intravesical pressure and the maximal rate of flow of urine, a function which he calls the Effective Urethral Cross-Sectional Area E.U.C.A. This represents

/the ....

the area of the simple orifice through which the bladder would empty in the same way as it does per urethram.

Electromyography

a) External Urethral Sphincter - Striated muscle

Petersen and Franksson (1955) showed conclusively the constant activity of the striated bulbo-spongiosus and external urethral sphincter. This activity increased when intra-abdominal pressure was raised, as by coughing, or when muscles were contracted voluntarily.

Voluntary relaxation of the external urethral sphincter can be achieved by some people, but not by others, according to Petersen et al (1955). Evidence suggesting that the external sphincter has a role to play in starting micturition is also presented by this group in the following experiment.

After preliminary training, which enabled this hardy band (nine males and one female) to void in company, and when recumbent or half sitting, 40 mg. of succinyl choline was injected. Shortly thereafter, when artificial respiration was necessary, there was considerable reduction in the electromyographic activity of the urethral sphincter and of the first dorsal interosseous muscle. Activity returned much more rapidly in the external sphincter than in the hand muscle.
A further injection of 10 mg. shortly after 40 mg. had caused reduced activity, led to complete paralysis of the hand muscle but some activity of the external urethral sphincter remained. None of the 10 subjects could void at will after the succinyl choline, despite their previous training, but, as soon as urethral sphincter activity began to return, the subject could start to empty his bladder and could also interrupt micturition within ten seconds.
One subject, to complicate matters, could both start and stop micturition after the activity of striated muscle had disappeared completely. It seems likely that in his training he became able to exert willed control over smooth muscle similar to that achieved by people who practice Yoga etc.

On the basis of this evidence it seems possible that the role played by striated and smooth muscle in the initiation of micturition varies from person to person. See also Section II, Part 5.

Flannery (1968) has shown that electrical stimulation of the anterior fibres of the levator produces vigorous contraction of the pelvic floor muscles. This leads to forward movement of the bladder base and neck, suggesting that the formation of the posterior urethro-vesical angle is a function of the levator ani. He also found that contraction induced in the pelvic floor muscles produced maximal urethral resistance thus keeping the urethra empty during straining. This work strongly supports the important function that the levatores and other pelvic floor muscles perform in maintaining continence.

Routine clinical procedures accompanied, when indicated, by pressure and flow studies including D.O.P. and E.U.C.A., electro-myography and dynamic cine-radiological screening provide the diagnosis, in most cases of urinary dysfunction. They also provide useful evaluation of the results of treatment.

b) Smooth muscle

Boyce (1952) has shown that normal electropotential changes can be recorded by electromyography from the bladder wall. Injury to bladder musculature, or interruption of its nerve supply, produces changes which can be readily identified on an oscillographic record.

PART 8.

FACTORS RELATING TO PARTURITION

The expulsive and resisting forces and the pressure changes in the uterus, recorded during parturition, are well summarised by Eastman and Hellman (1961) The role which they assign to the round ligaments in actively contracting and pulling the uterus into alignment with the cervix during labour is of interest. Their dismissal of the utero-sacral ligaments in this respect, however, is of questionable validity.

Eastman and Hellman (1961) produced graphic reconstructions of the distension of musculature during crowning which, although not quite accurate, give a clear picture of the enormous stretching of the fibres which must occur.

H. Roberts and Jeffcoate (1952) showed, by lateral cystourethrographic studies on women in labour, that movement of the bladder base and urethra depends on 'descent of the presenting part and not on dilatation of the cervix and lower segment. If the presenting part is arrested at the pelvic brim the

/bladder ....

bladder base and urethra remain in their normal positions irrespective of the length of labour or dilatation of the cervix. When the presenting part engages however, the bladder base is rolled up from behind forward, until it comes into line with the urethra. At the same time, some funnelling of the urethra is seen and this, coupled with the loss of the posterior urethro-vesical angle, closely resembles the picture seen in cases with stress incontinence.'

As Kegel (1948) pointed out ' when any large object is forced against a diaphragm with a smaller opening, the greatest stress is at the margin of the orifice, more peripheral areas being subject to less strain.' In the case of the ± 10 cm. diameter infant head in relation to the opening in the pelvic diaphragm, especially if relaxation is less than perfect, it is easy to imagine

a) the stretching and tearing of sphincter vaginae fibres and overlying superior fascia
b) injury to the perineal body
c) injury to the posterior part of the external urethral sphincter, which has been shown to occur, by electromyographic studies conducted through the vaginal wall, by Petersen (1955). Electrical activity was diminished or absent in this region in multiparous women as considered earlier.

Kegel (1948) also suggested two types of injury:

1) laceration and separation of muscles and fasciae
2) separation of individual muscle cells from the nerves by which they are innervated. This occurs because nerves are relatively inelastic compared with muscles and therefore become separated from their motor end plates and spindles. Shawe (1955) has clearly demonstrated the tremendous regeneration potential of injured nerves so that recovery from this is to be expected. Kegel further pointed out that suture and repair are inadequate as sole methods of treatment, because as Fischer has shown, an inactive, injured muscle will lose almost 80% of its weight whereas an active injured one, will only lose about 20% (c.f. quadriceps exercises). He regarded the regaining of perineal strength after childbirth as mandatory and his pleas for 'frequent repitition of correctly guided exercises' post-partem has not received anything like the support and universal acceptance which it merits.

/After ....

After all, if no expense is incurred, as a perineometer is not really necessary, and enormous suffering and embarrassment can be prevented by exercises, which even tribal communities have no difficulty in performing, a routine which extends far beyond enlightened centres should by now have been established. These graded exercises involve all perineo-pelvic musculature and produce simultaneous contraction of the external urethral sphincter, levator ani and external anal sphincter, all of which may have been damaged to a greater or less extent, during childbirth. It is hoped that no student leaves our Medical Schools without being able to prescribe and assess the effectiveness of such exercises.

Paracervical Blocks

Murphy et al (1970) considered the haemorrhage rate of six patients out of 36 unexpectedly high when paracervical block by the introduction of a needle and catheter through the lateral fornices into the base of the broad ligament was performed. One would imagine that the presence of the vastly complicated uterine plexus of veins anastomosing with the vaginal plexus (Plate 1.6) would make such an occurrence highly probable. The authors state that continuous paracervical block is now positively contra-indicated because of

a) foetal bradycardia in a substantial proportion (9 out of 36) and perinatal death following bradycardia (2 out of 36).
b) low success rate as 13 only, out of 36, had satisfactory analgesia. This is not surprising when one considers a) all the connective tissue, smooth muscle and vessels in the region which would favour non-spread of anaesthetic agents, b) the fact that somatic nerves are not anaesthetised.
c) the incidence of haemorrhage mentioned above.

INDEX

SECTION V

SECTION V

PART 1.

Failure of any of the pelvic viscera either

a) to remain wholly above the pelvic floor, or

b) contain their contents until expulsion is timely,

depends on distortions of normal anatomy which I shall attempt briefly to analyse. That imperfect physiological mechanisms may be causal in some cases cannot be denied.

DESCENT OF VISCERA

Many analogies between responsible factors can be drawn in this connection.

Thus loss of anchoring mechanisms due to

a) stretching, separation or changes in the connective tissues,

b) concomitant loss of tone in the smooth muscle of the pelvic fascia,

which normally holds and supports the pelvic organs, is of major importance.

Damage to the striated muscle of the pelvic floor by direct trauma or nerve injury, and the laxity of the floor, so clearly produced, as shown by Duthie (1969) and Parks et al (1966), with excessive straining, is undoubtedly causal in some.

Alterations of the more vital angles, ano-rectal (perineal flexure), posterior urethro-vesical and utero-vaginal appear to contribute substantially to this unfortunate phenomenon.

Finally diminution of elastic tissue and of the support afforded by fat in the pelvis and ischio-rectal fossae may be of significance in some cases. Prolapse of the viscera will now be considered:

1. Rectal prolapse
2. Prolapse of urethra
3. Uterine prolapse

Rectal prolapse

All the factors indicated above may apply in this condition. In addition, redundant loops of colon and an abnormally deep pouch of Douglas are frequently invoked, although it is questionable whether the one is not

/subsidiary ....

subsidiary to, and the other a consequence of, the prolapse. The major causes I think are

a) loss of anchoring which leads to loss of ano-rectal angle and

b) a relaxed condition of the pelvic floor, including the anal sphincter, induced as Porter (1962) and Parks et al (1966) amongst others have shown by straining and constipation.

The prolapse as noted earlier adds further inhibition. Straining is a major cause of prolapse in children (Nixon 1962). Scarring of pelvic floor musculature and neurogenic factors are clearly contributory in certain cases.

In young and elderly subjects, diarrhoea, as is well known, frequently precipitates prolapse when circumstances favouring it are present.

Treatment of Prolapse of the Rectum

Most of the remarks in Part 2 relating to the preservation of continence apply equally to the prevention of descent of viscera. Rectal prolapse patients especially, are notoriously prone to develop incontinence.

As prolapse occurs more frequently in institutions, where inmates have too little to do, or are mentally disturbed, preventive measures in the form of active exercise and perhaps electrical treatment might be of use in its prevention.

The literature on this subject is overwhelming. A recent review by Mann (1969) puts many of its facets into perspective. It is difficult to group operative procedures logically as most surgeons seem to have several aims in mind when they operate for prolapse. I shall list these aims and then consider briefly how various operations fulfil the expectations of their perpetrators.

a) Alteration of pelvic peritoneal floor. Since Moschowitz (1912) first advanced his sliding hernia of the Pouch of Douglas theory, obliteration of the deep pouch has been regularly practised.

b) Strengthening of a weak or inadequate pelvic diaphragm.

c) Compression of ano-rectum or anal canal or both.

d) Removal or plication of prolapsus or of apparently redundant mobile loops of bowel.

e) Suspension or fixation of the bowel with restoration of its normal anatomical relationships.

In particular cases, each of the above may have effected cure, but a

/critical ....

critical review of the available literature shows that (e) is the category which enjoys immeasurable advantages over all the others.

I shall briefly review the literature in a highly selective way and attempt to prove why the operation, which has proved most successful, deserves its acclaim.

Moschowitz's article (1912) is interesting, not so much for the theory which he advanced, as for his statements on hernia in general which strike a very modern note. He remarks the thick fascia on the undersurface of the levator although he does not enlarge on it. Since his time all surgeons have removed redundant peritoneum in relation to the recto-uterine or recto-vesical pouches.

At an R.S.M. meeting in 1933 Miles spoke of an 'internal organ persisting in its endeavour to become an external organ' and noted that eversion and extrusion of the wall of the rectum involved its whole circumference. He reported success with recto-sigmoidectomy followed by pelvic exercises. He treated his first case in 1904 and had 31 to date, 7 men and 24 women; only one had recurred.

Commenting, Gordon-Watson (1933) noted pelvic floor relaxation of severe degree in a percentage of patients which precluded the permanent success of any operation. He referred to electrical stimulation of the pelvic floor as carried out by Dr. Heald.

It is fascinating to read Roscoe Graham (1942) noting that the 'posterior wall of the rectum is carried forward from the sacrum making the rectum now almost a straight tube with the fascial supports most inefficient due to overstretching'. He claims that ideas on this mechanism date back further than Moschowitz to Jeannell in 1890. Although he believed that the anatomic defect was in the pelvic fascia he did not appreciate the parts most vitally concerned and his operation does not adequately restore the anchoring mechanisms or ensure that the bowel is replaced in its pristine position. Such success as he had was due largely to induced fibrosis.

Pemberton (1939) advocated thorough mobilisation of the bowel to the tip of the coccyx and then fixation so that a mass of scar tissue would hold it in its sacral bed.

Pemberton (1953) reviewed the records of all prolapse cases from 1910-1951 and the results of his own suspension fixation operation and recorded an 11.4% recurrence rate with this operation.

/Muir ....

Muir (1955), giving his Presidential address to the R.S.M., spiritedly invoked the past with its down to earth phraseology. Paré who wrote on the 'falling down of the Fundament' also quoted the Hippocratic treatment of hanging the 'patient by his heels' and shaking him until 'the gut by that shaking will return to its place'. Muir prescribed anterior resection as the treatment of choice.

Wiseman (1676) envisaged the Thiersch procedure when he fastened a tin hoop to a quilted bolster fitted with a bandage to be applied during defaecation and so prevent prolapse.

Muir's X-ray faecograms were very clear and he quotes Berglas and Rubin on levator myograms. He also showed his own pictures which illustrated some widening of the levator hiatus. This technique, as he admitted, was hardly contributory as decades of work had proved laxity at the ano-rectal junction.

Swinton and Mathieson (1955), amongst other procedures, felt that a modified Delorme procedure was the best treatment for severe degrees of prolapse in the elderly and frail. However, removal of rectal mucosa in such cases would tend to counteract the good effect of a contrived muscle ring reinforcing the anorectal one.

Goligher in 1958 introduced his well known modification of Roscoe Graham's operation, which has enjoyed a fair measure of success due to the scar tissue it engenders. He reported no recurrences in 23 patients followed up for seven years. As recurrence is usual within a twelve month it is a very fine record.

Shann (1959) gave an historical review of operations for prolapse and referred to Bacon's excellent review, which I have been unable to obtain. He concluded that a knowledge of normal anatomy was what is required if the condition was to be adequately remedied. His own description of ano-rectal anatomy shows room for improvement as the following instances demonstrate. He does not mention the relations of the pelvic fascia to the ano-rectal junction nor the attachment of levator fibres to the bowel wall. He comments on how at the perineal flexure the 'anterior wall becomes the posterior wall and fits snugly under the pelvic floor.' The anal canal, he says, because it is not a pelvic organ, is placed under the pelvic floor. "This is very important. It has no muscular support except for a thin

/perineal ....

perineal fascia, is practically a subcutaneous structure and is therefore vulnerable in the sense that it is easily displaced from its normal location".

Few must have realised the significance of C. Wells' (1959) announcement that, to the already considerable number of operative procedures available for prolapse, he had added one more. Research by Wood (1962), among others, had shown that polyvinyl alcohol sponge (Ivalon) induced fibrosis and itself finally disintegrated and became incorporated in the tissues. Wells described his technique of fully mobilising the rectum and anchoring the terminal bowel to the sacrum by means of an Ivalon sponge wrapped three quarters of the way round the bowel.

In 1962 at an R.S.M. meeting C. Wells presented his successful results and recorded no mortality. Naunton Morgan noted the improvement in results achieved by Wells's method and described his own success with it. At the same meeting Hughes and Gleasdell (1962) reviewed an operation, which they describe as essentially similar to the Graham-Goligher-Snellman procedure, differing only in the way in which the levator is sutured. (Snellman added suturing of the rectum to the sacrum, to Goligher's operation. I have not been able to obtain Snellman's account). However, they added perineorrhaphy and did not mention anchoring the bowel to the sacrum. They claimed good results for their procedure which seems fully to mobilise the rectum. In their illustrations the sutures in the levatores look as if they could easily damage the urethra or the prostatic plexus of veins.

Todd (1962) at the same meeting predicted the 'descending perineal syndrome' and remarked poor rectal sensation pre- and post-operatively in these cases. His comments, as usual, were pertinent and wise. The rectum should be mobilised and put back where it belongs. Rectal sensation must be preserved and plication of overstretched muscles would do no good.

Muir (1962) at the same meeting firmly defended his anterior resection. He reported no recurrence in eight patients over six years.

Backer and Baden (1962) did a modified Pemberton which fastened the rectum to the anterior longitudinal ligament on the promontory of the sacrum.

Beahrs et al (1965) carried on Pemberton's study from 1951-1962. 86 of those reviewed, who were mainly female and ranged in age from 18 months to 81 years, were treated by one of three procedures:

/ Pemberton's ....

Pemberton's operation - 52

Anterior resection and Pemberton's fixation - 19

Altemeier's one stage repair - 15

The recurrence rate with Pemberton's method had risen to 34.6% from the original 11.4%. No recurrence followed anterior resection and fixation, and, with Altemeier's one-stage procedure a 20% recurrence rate was recorded.

Thomas and Jenkins (1965) noted again the alteration in physiological mechanisms with poor internal sphincter response. They also stated that inhibition of the external sphincter was produced more readily, more completely, and for a protracted time - all facts established by Porter (1962). They recommended a posterior approach of Kraske type through which, if necessary, redundant bowel could be removed.

Devadhar (1965) described a 'crucial point' at which intussusception occured due to 'powerful muscular forces'. By longitudinal plication of the rectal ampullary wall he claimed that 28 patients had been treated. Mucosal laxity, due to sphincter deficiency, was treated by a Thiersch silver wire in occasional cases. He believed the prolapse to be the cause of a wide levator hiatus and not the result of it. He did not invoke anchoring factors.

Ripstein (1965) claimed that he had restored the ano-rectal angle by wrapping teflon round the rectum and fixing it to the hollow of the sacrum. The rectum thus was 'unable to pass straight downwards and prolapse' - an echo from Roscoe Graham. His results with this procedure were very good.

Parks (1967) proposed the building up of a muscle bar behind the anal canal to restore the ano-rectal angle and improve continence. His operation is designed to raise the pelvic floor in this region and consists of finding a plane behind and lateral to the anal canal between it and the 'external sphincter, pubo-rectales and levator ani' and then entering the 'true pelvis by division of Waldeyer's layer'. Then a repair in layers is performed and the external sphincter is tightened. Such a procedure must sever the bowel from the levator contribution to the conjoined coat behind and laterally divide pelvic nerves and injure all the layers of the ano-coccygeal raphe. In addition abundant sutures are placed in muscle, which already has reduced tone and efficiency, and it is now required to overcome further

/handicaps ....

handicaps. He noted that this repair is easily disrupted by defaecation and straining. Such an operation is anatomically unsound and his good results are unexpected.

Naunton Morgan and Porter (1969) reported results with Ivalon sponge implants noting that, in 100 cases only one recurred, and continence was improved in 50%. The excellent fixation was remarked and the restoration of the levator shelf. There was still a place for a Thiersch type of procedure in poor risk patients they believed.

Their excellent results have been corroborated by A.A. Brown of Cape Town amongst others.

The plane of insertion of the Ivalon is behind Waldeyer's fascia but above the muscle of Treitz and the levator ani muscles. On each side of the bowel the sponge is threaded through Waldeyer's layer and lightly anchored to the bowel wall leaving a gap in front. The measurement between the direct offsets to the bowel wall from the pelvic nerves and the ano-rectal junction is about 4 cm. in the adult cadaver and these must pass to the bowel just above the sponge. The measurement at operation is doubtless longer than 4 cm. The sponge is also attached to the front of the sacrum. In the course of this part of the procedure the median sacral veins are prone to be caught in sutures and ooze.

Careful extra-peritonealisation of the Ivalon is then achieved and redundant colon is anchored on a broad base so that it does not twist.

Conclusion

The fibrosis induced by the sponge results in anchoring of the ano-rectal junction thus simulating the combined efforts of the

1) ligament of Treitz,
2) Waldeyer's fascia, and
3) the superior fascia of the levator.

In addition replacement of the rectum in its sacral bed restores the ano-rectal angle so that a fair chance exists that normal physiological function will return.

Treatment of Prolapse in Children

Jackman and Cannon (1949) strongly supported conservative measures in infants and children up to six years. Prolapse appearing for the first time after five years should be treated in the same manner as it is in adults.

/This ....

This view is also endorsed by Nixon (1962).

Prolapse of the Urethra

This is extremely uncommon and is usually due to some congenital deficiency of the urethral wall, or, in later life, may follow loss of elastic tissue support. A few cases of ureterocele prolapsing through the urethra have been recorded (e.g. Emmet J.L. and Logan G.B. (1944)). This condition will not be considered further.

Prolapse of the Uterus

According to Smout and Jacoby (1948) in 99% of cases with prolapse, child-birth is the major cause of descent and in 1% there is congenital weakness of the pelvic floor. This is usually associated with spina bifida occulta. The work of Mengert (1936), who employed a method used in 1858 by Legendre and Bastien, of traction on the uterus of a cadaver to find out what structures retained it in the pelvis is of interest. They found that (with a 1 kg. weight suspended from tenacula inserted into the cervixes of autopsy specimens so that a straight pull was exerted) division of the round ligaments, infundibulo-pelvic and ovarian ligaments and upper third of the broad ligament caused no descent of the uterus. Even division of the lower two thirds of the broad ligament did not allow more than slight descent, but, when they added division of the paravaginal fascia, which is depicted in a most unrealistic way in Fig 1, descent followed immediately. They therefore concluded that the paravaginal tissues, helped by utero-sacral and lateral ligaments (lower two-thirds of broad ligament) were responsible for holding the uterus in position.

The reason for their findings I imagine is that the superior fascia of the levator joins the vaginal wall, accompanied by a number of its underlying muscle fibres, and, posteriorly, the fascial layer of Waldeyer with its ligaments anchors the vagina and cervix. Their conclusion about the unimportance of the pelvic floor is based on incorrect anatomical premises. They rightly discounted the so-called 'pubo-cervical' ligaments and showed that the round ligaments were unimportant in holding the uterus above the pelvic floor. They must however be useful in preventing rotation of the organ.

Most cases present for treatment in the post menopausal era when

/endocrine ....

endocrine and vascular influences are also operating. Descent is especially notable in relation to the vaginal wall. Well known cystocele and occasionally urethocele appears in front, and rectocele behind, suggesting that trauma of the pelvic floor, and loss of the anchoring provided by the perineal body and levator are the main causes of the condition. These deficiencies are frequently aggravated by increased intra-abdominal pressure due to lifting, coughing, straining and gross increase in weight.

Loss of the utero-vaginal angle leads in some to procidentia. Exceptionally, eversion of the uterus occurs especially following traction on the placenta or when rise in intra-abdominal pressure is associated with laxity of smooth and striated muscles.

Surgical treatment of Uterine Prolapse

Unquestionably, unless alignment of the uterus and vagina can be proved, or when the cervix protrudes through the vulva, or when hysterectomy for some other cause is indicated, the treatment of prolapse is best achieved by vaginal operation (Shaw, (1954)). This should be supported, when indicated, by some form of fixation. See Part 2.

This fact highlights the importance of the utero-vaginal angle and the pelvic fascial supports as, when these are removed, prolapse may be gravely aggravated.

FOOTNOTE

It is noteworthy that Imianitoff (1928) recommended electrical treatment of retroversion. He noted a round ligament reflex and the same stimulus produced tautening of the utero-sacral ligaments. The details of the treatment are difficult to follow as the information was abstracted from a Belgian journal. Recent advances in electronics might make exploration of this way of improving smooth muscle tone and hence anchoring worthwhile. It might prove a useful measure subsidiary to exercise in returning the pelvis to normal after child-birth.

PART 2.

CONTINENCE

Definitions

a) Faecal. Gaston's (1951) definition still seems the most apt: 'faecal continence is the ability to retain the contents of the colon until their expulsion is convenient'.

b) Urinary. Transposing words - urinary continence is the ability to retain the content of the bladder until its expulsion is convenient.

c) Uterine. The ability to retain the menses and the products of conception. Here biorhythmical and endocrine events determine the elimination of the first and the expulsion of the latter.

General Factors Controlling Continence

The factors involved in continence of all the viscera which traverse the pelvic floor are manifold but may be summarised under the following headings:

1. The integrated striated musculature of the pelvic floor with its sensitive, partly valvular, partly sphincteric mechanism, anchoring potential and other general and particular functions described at the end of Section II.

2. The smooth muscle compliant reservoirs of the rectum, bladder and uterus, each of which is connected by an important angle to its outflow channel which passes from pelvis to perineum. This smooth muscle permits viscera to accommodate to changes in volume with minimal changes in transmural pressure. It can do this because of its elastic behaviour, stress relaxation, active but intrinsic changes in muscle tension and reflexly mediated contraction and relaxation. It is especially sensitive to stretch. Contraction waves may exhibit a 'reverse pressure gradient'.

In addition the baffle plates formed by the valves of Houston in the rectum in relation to the lateral curvatures, the subpubic 16^{o} angle in the urethra and the anteflextion of the uterus play a subsidiary role in relation to each of these organs.

3. Neural factors - sensory receptors are located in mucosa, submucosa and in smooth and striated muscle layers and in adventia in relation to each of the organs.

Such receptors enable viscero-visceral reflexes, both intrinsic and extrinsic, viscero-somatic reflexes between pelvic organs and striated musculature in many different regions, somato-somatic and even somato-visceral reflexes to take place.

Only the uterus and vagina can function efficiently without nervous control.

4. The connective tissues embodied in the anchoring factors described in Section IV, Part 2 and in the cervix itself, contribute substantially to its maintenance.

/5. ....

5. Precise occlusion of the lumina of the tubes is achieved by smooth muscle by venous plexuses of notable proportions, which are strategically placed for this purpose, and these are helped by abundant elastic tissue to effect air and water tight seals.

INCONTINENCE (Faecal)

Reviews summarising much of what is now believed about 'anal' incontinence, which is surely better termed 'faecal' incontinence, its causes, symptomatology, investigation and treatment have recently appeared by Duthie (1969) and by Hardcastle and Porter (1969). It was disappointing to find most of the articles which I had collected from the literature presented in these fine articles. Duthie, who has made major contributions to our understanding of ano-rectal sensation makes one statement which is not anatomically permissible. It is that 'the flaccid antero-posterior slit of the anal canal was thought to be occluded just below its attachment to the levator ani muscles by transmitted intra-abdominal pressure'.

I propose now to outline measures which can be taken to

a) preserve continence,

b) promote it and

c) restore it

the first two being worthy of the most serious consideration in view of the importance of this priceless faculty.

a) Preservation of Continence (Ano-Rectal)

i) Prophylactic

Education in personal hygiene could largely control infections in and around the anal canal and the consequences which may attend their treatment.

It should be possible to eliminate constipation and excessive straining as a cause of lax perineum with its attendant dangers.

Obstetrics directed towards full relaxation of pelvic floor muscles through controlled breathing during parturition and followed up by active perineal exercises in the puerperium is still not as commonplace as one might expect it to be.

All the well-known causes of increased intra-abdominal pressure, including excessive weight, which act adversely on the pelvic floor and its apertures, need to be handled promptly as they arise.

ii) Surgical

Episiotomy when indicated; and accurate diagnosis and repair

/of ....

of perineal injuries, including reconstitution of the perineal body under propitious circumstances, as advocated by Chassar Moir (1959), can do a great deal to ensure that continence is preserved.

In the performance of ano-rectal procedures Bennett and Duthie (1963), Bennett (1962), Bennett and Goligher (1962) have drawn attention to change of

a) sensation in the area
b) pressure in the anal canal

which account for minor deficiencies of control, although, as Duthie (1969) has pointed out, there is a wide range of what is acceptable as continence in the population as a whole.

Haemorrhoidal scars may produce areas of reduced sensation and damage to sphincteric apparatus can reduce pressure.
Duthie et al (1963) found that, following operations for fistula-in-ano, a diminution in pressure occurred in the lower 2 cm. of the anal canal in both low and high cases. In the low group there was a significant rise in pressure in the remaining undivided muscle as a compensatory mechanism. In the high group pressures were drastically lowered and extensive scarring led to sensory changes as well. Relaxation of the internal sphincter was also interfered with in some, so that the warning device became less efficient. According to Bennett and Goligher (1962) 43% of patients after orthodox treatment of anal fistulae had some defect - they however did not find site of division of the sphincter to correlate with degree of disability. In a small number less defect in continence was noted when the sphincter was divided elsewhere than in the mid-line posteriorly. Bennett (1962) ended one talk on this subject with a cynical comment to the effect that it was not much comfort to a patient to have his yellow discharge exchanged for a brown one.

In view of the above findings it is amazing that a transphincteric, transrectal approach to recto-prostatic fistulae could have resulted in full continence in four patients reported by Kilpatrick (1969).

Technique of excellence in so-called minor ano-rectal surgery, based on sound anatomical knowledge, is a sine qua non.

/b) ....

b) Promotion of Continence

In Adults

i) Sensory Preservation

Malignant Disease. Gaston (1951) was the first, seconded by Goligher (1951) to appreciate the importance of preservation of the lower 6 - 7 cm. of rectal mucosa in the promotion of full continence. Goligher noted that no patient with an abdominal colostomy ever develops a rectal type of sensation. On the other hand, when colon is drawn down into the pelvis, in sphincter sparing procedures, the pressure of distended bowel on adjacent structures may lead to some degree of sensation, although, unless sufficient rectal mucosa remains, this is unlikely to be reliable.

Gross diminution of the pressure zone in the anal canal is found when the rectal stump is $<$ 6-7 cm. long.

ii) Sparing of Sphincter

1. Benign Lesions According to McLean and Arminski (1959) the posterior surgical approach to the rectum was devised by Kraske in 1885, modified by Hochenogg in 1888 and Kirschner in 1933. They recommend this approach alone, or combined with abdominal mobilisation, for lesions such as polyps and strictures which are sited in the lower part of the rectum. In the course of the operation they remarked the dense fascia, between the sacrum and bowel extending up to the promontory of the sacrum, which is clearly Waldeyer's layer of fascia.

They believe this approach has considerable advantages in preserving the sphincter mechanism.

2. Malignant Lesions. Maingot (1948) lists those who, by their judgment, courage and exquisite skill, have played a leading part in perfecting these operations. Today Muir's (1939) anterior resection, which according to Maingot (1948) was based on Hartman's 1923 operation, is a well established method of treatment for tumours of the upper third of the rectum, which yields perfect functional results. There is occasionally a place for localised resection of polyps or other lesions of any part of the rectal wall. As Goligher (1965) remarked, the difficult cases are those in

/which ....

which a tumour is located in the middle third. For such cases, if anterior resection is not feasible because 4-5 cm. of microscopically normal bowel cannot be left distal to the lesion, he gave his assessment of abdomino-anal pull-through excision as described by Turnbull. Only 39% became fully continent of faeces, the rest however seemed able to manage their perineal colostomies reasonably well.

This pull-through procedure he recommended as useful for adult Hirschsprung's disease, recto-vaginal fistulae following irradiation proctitis and prostato-rectal fistulae following prostatectomy.

In Children

Two operations, which make use of similar principles and which have been modified and improved on by many authorities, commend themselves particularly because of the minimal disturbance of normal anatomy which they create. They are:

1. The combined sacro-abdomino-perineal approach to high ano-rectal anomalies, e.g. ano-rectal agenesis with recto-urethral fistula.

a) The abdominal part of the operation leaves the ano-rectal junction and its vital anchoring mechanisms, including the perineal body, undisturbed. The septal layers are intact to carry their autonomic nerves and middle rectal vessels to the bowel wall. This is especially important when, as Scott (1959) has shown, in cases with high anomalies the pelvic nerves and plexuses lie nearer the mid-line and closer together than in the normal infant. His studies demonstrated the fact that ganglia and nerve fibres are usually plentiful in these cases and therefore every effort to preserve them should be made. The myenteric plexuses remain to control bowel function and, as noted earlier, in some, the internal sphincter retains sufficient innervation, to enable it to react normally to rectal distension.
Coring out of the mucosa of the blind pouch allows the fistula to be closed off flush with the muscle wall.

b) The sacral part of the operation allows accurate visualisation of the levatores and pubo-recto-anales and frees the coccyx so

/that ....

that the levatores and sling complex approach the bowel, pulled forward by their pubic attachment and perhaps by some accompanying shortening of the arci of the levatores. This ensures a well defined ano-rectal angle with a shelf of muscle behind it.

c) The perineal part enables sphincter fibres to be accurately defined. Pre-operative electro-myography may also help with this.

Co-operation between operators ensures that the correct plane, anterior to cranial and caudal levator fibres, is employed for the pull-through. In addition the perineal operator can construct a proctodaeum to dovetail with the pull-through as first suggested by Nixon (1964) endorsed by Kiesewetter (1967) and amplified by Hiatt and Santulli (1962).

Thus the final requirement of sensory preservation is partly met. Rehbein (1967), with commendable modesty, gave credit to Rhoads et al (1948) for their foresight in introducing an abdominal as well as a perineal approach in these cases. Stephens (1953) first explored the sacral approach in infants and this has provided another major advance for the reasons listed. The importance of not missing the pubo-recto-analis sling has been reiterated on innumerable occasions, but, less well known is the syndrome described by Innes-Williams (1969), which he calls the 'pulled-up' bladder. This follows posterior mobilisation of the bladder and urethra in order to close off the fistula flush and ensure that the bowel is correctly placed. The anterior wall remains fixed, a curious lip formation appears at the neck and there is loss of the posterior urethro-vesical angle. Y-V plasty of the anterior bladder neck has proved curative.

Despite every known measure and perfect technique some of these cases do not do as well as they might. In such cases the possibility of associated aganglionosis has always to be considered. Vanhoutte (1969).

2. Soave's operation for Hirschsprung's Disease

Soave in 1964 described an operation for Hirschsprung's disease also based on the Rehbein principle of defining a plane of cleavage

/between ....

between the muscularis and submucosa.

Soave as he extended his plane downwards towards the dentate line described adhesions, which must be snipped with scissors, which are likely to be conjoined coat-tails passing in to the submucosa. The beauty of this operation lies in:

a) sparing of levator ani, 'sling complex', and external sphincter

b) preservation of anchoring and supporting mechanisms

c) intact septal layers for the conveyance of vessels and nerves

d) sparing of sensory zone.

Soave claimed that his operation spared pelvic innervation together with hypogastric, lumbosacral and sacral plexuses, which makes one wonder how clearly he appreciated the anatomy of the region.

In America this is known as the Soave/Kiesewetter technique and in Britain Nixon's name is also associated with the operation. It is the operation of choice at the Red Cross Hospital in Cape Town. Soave (1966) finds that the results of his operation compare very favourably with those of Swenson and Duhamel. He introduces a variant of his technique and gives some highly impressionistic illustrations of muscular arrangements.

c) Restoration of faecal continence

No procedure can replace sensory receptors which have been removed or damaged.

Operations: These have been described in Duthie's carefully considered 1969 article. I shall comment briefly on a few other procedures and consider Kottmeier's procedure in more detail.

1. The chromic ribbon gut constriction method of Lowsley and Hunt (1939) would be very liable to cause infection and obstruction.

/2. ....

2. Ingelman - Sundberg (1951) has devised a way of dividing pubo-coccygeus at its middle and then wrapping it round as a pre-anal strap to replace the external sphincter. It depends for its success on the innervation of the muscle from above.

3. Pickrell et al (1959), under Anatomic Considerations, note that the pudendal nerve arising from 'S3 and 4' leaves the pelvis through the 'lesser sciatic notch'.

The illustrations of the operation are however very clear as are his operative instructions.

They claim success with this method in 50 children.

The addition of electrical stimulation of the gracilis implant appears to hold out the possibility of improving its function.

4. Loygue and Dubois (1964) describe causes and review a number of surgical methods.

Failing direct repair of an injured sphincter they favour the gracilis muscle transplant designed by Pickrell et al (1959) although they are not as sanguine about results.

5. Kottmeier (1966) writes on secondary repair of anal incontinence in patients with imperforate anus. He advises the formation of a 'modified levator sling', which is excellent in principle. He shows in Fig 1. a cranially sited puborectalis and an anatomically untenable entity in Fig 2. The origin of levator ani must be continuous therefore a gap in the pelvic floor, as illustrated, could not exist. Fig 3. shows an incision, which must divide the nerve to levator ani, the lack of which may be made good, by the branches which it receives on its perineal aspect.

Damage to these nerves may be the reason why two of his three first patients were not completely continent although, the cited reason of absent rectal sensation, is certainly valid.

Bors (1952) concluded that his results with pudendal nerve stimulation suggested that those authors were correct who deny that this nerve innervates the levator.

Although this supply is irrefutible, it is somewhat variable, and it is possible that in some cases the division of the nerve to levator ani might weaken the muscle seriously.

Kottmeier's 1967 diagrams have improved. He claims good functional

/results ....

results in his cases.

Conclusion

There is no doubt that freeing of the coccyx, as is performed in the sacro-abdomino-perineal approach to high ano-rectal anomalies, is of value because it releases the sling complex and other medially placed levator fibres which can move forward to form a snug collar behind the ano-rectal junction. This division alone is sufficient in such cases to restore the ano-rectal angle and at the same time leaves the nerves to the levatores intact.

Urinary Incontinence

I shall consider only incontinence caused by traumatic lesions in this section.

Preservation

The remarks made in relation to faecal incontinence are largely applicable in this context especially those referable to obstetrics. Careful attention to endocrine factors in the elderly can be a useful preventative measure.

Promotion

This will be considered under two headings:

a) Operations which jeopardize continence; how caused and how best prevented

b) Preservation of Sensation.

a) Operations which jeopardize Continence

Pelvic operations, especially abdomino-perineal resection of the rectum and Wertheim's hysterectomy, are frequently attended by urinary complications of which incontinence is the most distressing. The causes of the incontinence are still in debate but two factors seem to stand out clearly. They are:

i) injury to the pelvic parasympathetic nerves

ii) loss of anchoring.

Rectal Resection

Simmons (1938) believed that the common occurrence of retention of urine after rectal excision was due to sympathetic over-activity after injury to the nervi erigentes. In his series 22 cases, 15 male and 7 female, had presacral neurectomy at the time of operation and

/all ....

all escaped post-operative retention with its attendant risk of urinary infection.

Kickham and Bruce (1939) noted that the incidence rose with the advance of malignant disease and might also follow nerve injury. They stated that it occurs 'very commonly'.

Ewart and Hoffman (1944) stated that the most frequent complication was difficulty in emptying the bladder. This they believed was due to loss of support. Neurogenic complications they stated are 'happily transient'. In a significant series of large bowel operations, those involving the rectum, showed the highest incidence of urological complications. They drew attention to 'slight contractions of the bladder neck' as a cause and recommended transurethral resection for such cases. Of 833 abdomino-perineal resections 81 had post-operative difficulty in emptying the bladder and of these 44 males needed transurethral resection.

Marshall et al (1946) found that a high incidence of vesical dysfunction followed removal of the rectum by abdomino-perineal or the perineal route alone. Yet the incidence was low if the perineal dissection was omitted. Traditionally this was ascribed to damage to nerves but no specific neurological changes were demonstrated in their series. Most of their cases had mobility and marked sagging of the vesical base, which suggested that lack of elevation and fixation might be this unrecognised factor. They cited a male of 54, who after two transurethral resections, which they claim did not involve the external urethral sphincter, was totally incontinent. Suspension and fixation alleviated his condition permanently.

McKrea and Kimmel (1952) gave a 6.9% incidence, or 39 of 558 cases, in whom urological complications developed after abdomino-perineal resection. In no instance, they stated, had the female bladder failed to return to normal function. They attributed this low incidence to the presence of their accessory nerves referred to in Section IV.

Watson and Innes-Williams (1952) described, in two out of 50 cases of rectal excision, a pelvic nerve syndrome in which retention was followed, in a few days or weeks, by total incontinence and often severe urinary infection.

/In ....

In these cases they felt the removal of the levatores, loss of angle and displacement might be significant in addition to imbalance of autonomic nerves. In Fig 22 they noted that the falling back of the bladder base and prostate after combined excision of the rectum had the perineal membrane as the fulcrum. They meant in fact the urogenital diaphragm. Seven out of nine females with nerve damage had had hysterectomies before, or at the time of rectal excision. This suggests that the uterus and septal layers afford a definite protection to the nerves. In these cases pelvic exercises can be of the utmost value. Hypertrophy of the striated musculature including bulbospongiosus was referred to earlier.

To empty the bladder abdominal compression, which raises the intravesical pressure, is of acknowledged value.

Williams and Grant (1969) noted similar findings in children after operation for high anomalies especially, and recommended similar treatment. In one such case they had success with an electrical implant.

They stressed again the importance of X-rays pre-operatively to determine degrees of sacral agenesis, because, as one of them had noted previously (Williams and Nixon 1957), lack of three sacral pieces was almost always attended by a deficient nerve supply to the bladder. Durham Smith (1963) noted that neurological deficit in general paralleled that 'expected from the vertebral deficit'. He recorded the occasional unexpected finding of sacral nerves being present in the absence of corresponding vertebral segments. He also cited a case in which the pudendal nerves arose from one side and then crossed over to the perineum of the opposite side.

Hill et al (1937) sent out questionnaires to proctologists. Those who answered recorded from 0 - 100% of urinary complications following rectal resection. These authors are among those who favoured vesical nerve injury as the main cause. They showed changes in cystograms, normal pre-operatively, which included unilateral ballooning of the bladder, unlikely to be due to any cause other than nerve injury. Diverticula, which developed in the bladder wall within two weeks of abdomino-perineal resection, were also illustrated.

/In ....

In the discussion, which followed this paper, Smith (1937), said that in 90% some vesical dysfunction was present post-operatively, which in most was transient, and in some might take up to six months to clear. He drew attention to the need to examine the prostate for enlargement in these cases. This is of course routine practice.

Rankin (1969) in a searching review and with many useful references, noted that Miles and Lockhart Mummery recorded a high incidence of such complications. He investigated a group of 96 patients operated on at St. Marks' using the vesical pressure (DOP) and urethral cross-sectional area (EUCA) measurements outlined in Section IV, part 7 B. His conclusion was that parasympathetic denervation of the bladder is the main cause of bladder dysfunction after rectal surgery. It occurred in 21% of males and 29% of females. His enquiry, which is of a high order of precision, tips the balance in favour of nerve injury.

Wertheim's Hysterectomy

A BMJ leader (1969) drew attention to the incidence of urological complications which may follow this operation. Smith et al (1969) analysed 211 patients and found that 39% had incontinence of some degree. They showed again the exceptionally clearly defined parasympathetic nerve with its offsets, which featured in the 1968 article. They remarked that injury to the nerve was most likely where it was related to the lower aspect of the uterine artery. They again emphasised their point about the nerves to the bladder passing outside the pelvic fascia referred to in Section I and Section IV.

Hanley (1969) in an article based, as he admits, largely on subjective impressions, attributed urological complications to the practice of total, as opposed to sub-total,hysterectomy. Loss of bladder supports and descent of the trigone shown radiologically, were considered likely causes. He wondered whether total hysterectomy in nullipara was always necessary if cervical smears were taken regularly. He also conceded that much depended on surgical technique as descent of the trigone was not invariable after total hysterectomy.

In considering his arguments one has to admit that the lack of urological complications after sub-total hysterectomy might equally

/be ....

be due to sparing of nerves in the septal layers.

Discussion

On balance the evidence seems heavily to favour nerve injury as the most likely cause of incontinence of urine following pelvic surgery with loss of anchoring playing a major role in some cases and probably aggravating the condition in all cases. Special attention to avoiding these nerves at operation by keeping as medial to Waldeyer's layer and therefore as close to the peritoneum as possible is clearly desirable. Cognisance of their position is of value. Electrical means, which aid in their location, may reduce the incidence of this complication in some.

There are two factors which militate against preservation of nerves in many of these cases. They are firstly the striking increases in connective tissue which develop in the diseased pelvis and make identification of nerves difficult or impossible. Secondly, the need to radically extirpate malignancy, although, lymphangiography has shown how fallible this may be (e.g. Hahn et al, 1963).

Simple procedures to restore anchoring may find a place in management when indicated at the time of operation.

b) Preservation of Sensation

R. Turner Warwick et al (1967) found that, when they performed sub-total cystectomy, the preservation of a cuff of 1.5 cm. round the internal urinary meatus usually preserved adequate sensation. The patient could then recognise when the bladder was full. Nocturnal incontinence was thus avoided and the essential sensory and sphincteric elements of normal micturition were retained. When uretero-caeco-cystoplasty has been done an increase in urethral resistance may have to be overcome by abdominal pressure and in some cases sphincterotomy.

Restoration of Urinary Continence

Methods of reducing and increasing urethral resistance and of reducing and increasing vesical pressure have been noted. I shall consider mainly the treatment of stress incontinence in females and incontinence following prostatectomy in males.

/Stress ....

Stress incontinence in women.

This commonly follows injury to the striated sphincteric musculature of the pelvic floor as outlined in Section IV, Part 8. It may also be due, as Aldridge (1952) remarked, to excessive intravesical pressure due to such causes as pelvic tumours or a pregnant uterus, or reflex irritability of the bladder due to inflammatory lesions of the BOWEL.

Recent work by van Rooyen (1969) suggests that changes in the fascial capsule of the bladder and in the pubo-vesical and lateral ligaments are partly responsible for the stress incontinence which may first develop in the early months of pregnancy. These changes are:

a) Hypertrophy of collagen fibres which appear three to four times larger than those of non-pregnant individuals.

b) Enlargement with altered staining of the nuclei of connective tissue cells.

These changes may be part of a widespread effect produced by relaxin on the ligaments and connective tissues of the body although the identity of this substance is still undiscovered (Danforth 1966). Persistence of the complaint in women many years after pregnancy may be due to some damage to striated muscle and to laxity of the pelvic fascia. Especially involved is the superior fascia of the levator

a) where it swathes the pubo-vesical ligaments

b) where it joins the urethral wall and encircles it to reach the perineal body

c) where it forms the suspending lateral ligament of the bladder.

The resultant Green Type I or II cases may maintain an intact perineal body and commonly do not exhibit cystocele or urethrocele. The rationale for many of the operations so carefully described by Ullery (1953) especially that of Marshall, Marchetti and Krantz (1949) is thus revealed.

A formidable procedure involving detachment and re-attachment of the whole deep pouch in certain cases of stress incontinence is advocated by McConnachie (1968). His illustrations take no account of the disposition of the ischio-cavernosus muscles and crura and no mention is made of the cavernous nature of the tissue divided.

Treatment. The probable success of any suspension procedure can be

/predicted ....

predicted by raising the trigone towards the pubis, without compressing the urethra. This will relieve stress incontinence in favourable cases. This procedure was first described by Bonney and adapted by Marshall et al (1949) amongst others. Van Rooyen (1969) uses a slight modification of the Marshall, Marchetti and Krantz operation, which reconstitutes anatomical relationships of the pubo-vesical and lateral ligaments. This indirectly restores the posterior urethro-vesical angle. He claims a cure rate for 65 cases of 89.1%.

Pereyra and Lebherz (1967) have developed a method which in 210 cases has resulted in a 94% cure rate. After catheterisation the anterior vaginal wall is opened and a finger placed alongside the urethra. The point of a special eyed cannula is introduced through the anterior abdominal wall and cave of Retzius and, by feel, guided through the para-urethral tissues to the right of the urethra into the vagina. It is then threaded with one end of a piece of chromic catgut and withdrawn a few centimetres. The stylet of the cannula, which is also eyed, is then advanced, again by feel, through the paraurethral tissues at the level of the bladder neck and threaded with the other end of the piece of chromic catgut. The cannula is now withdrawn and the two ends of catgut clamped and laid aside. The cannula is now advanced through the same wound again and the performance repeated on the left side of the urethra. The area of the bladder neck is now repaired by exerting traction on the catgut pulleys and an anterior colporrhaphy is effected, taking care not to catch the parasagittally placed catgut stitches with the transverse ones, which might strangle the urethra. The catgut pulleys are finally tied to each other and buried in the subcutaneous tissues. The authors claim that no injury or sloughing or obstruction to the urethra can result from this operation. Fibrosis should be induced by the catgut which appears anatomically sound. The dimensions of the urogenital diaphragm in the female make this procedure feasible.

As most authorities seem agreed that vaginal operations are to be preferred in stress incontinence, a manoeuvre, which employs the vaginal route, but is supplemented by a safe procedure, which embodies the best of the abdominal procedures, without the addition of a

/laparotomy ....

laparotomy, has many obvious advantages. Occasionally a formidable cluster of outlying vesical veins in the retropubic space is encountered and any hint of vulval varices would be a strong contra-indication to this procedure. If the results are as excellent as these skilful workers claim, and especially if they are maintained, this procedure might perhaps become more widely used. Electrical means of restoring continence are noted in Section V.

Post-Prostatectomy Incontinence in the Male

In the male incontinence following prostatectomy is a rare but highly undesirable complication.

Stewart et al (1964) reported on their results with the Berry operation, in which a plastic prosthesis is placed between bulbospongiosus and the bulb, with the object of compressing the bulbar and lower membranous urethra. They had four perfect and five good results in a series of 13 patients. Their thesis that the prosthesis simulates the elastic collar, noted by Pennington and Lund (1960) at the junction of the prostatic and membranous urethra, seems unlikely to be a correct one on anatomical grounds. It may be that restoration of the subpubic angle of the urethra as it passes into the bulb, coupled with fibrosis induced by the plastic, restoring anchoring of the urethra, may be responsible for the successes in this series. This is perhaps analogous in some respects with the success of Ivalon sponge in rectal prolapse.

Uterine Incontinence

Measures to preserve and promote continence of this organ are not available as the causes are largely speculative.

It is highly significant I think, that the cervix, which must withstand the strain of retaining the conceptus, is made up largely of fibrous tissue and contains but little smooth muscle (Danforth 1966). This bears out the role of connective tissues in taking weight and withstanding strains emphasised in Section I.

Habitual Abortion. Occasionally, either due to extensive scarring, disease processes, or because of some innate deficiency of the cervix, due perhaps to endocrine imbalance, it is incompetent and repeated abortions at 12 weeks or over ensue.

/Histological ....

Histological studies of such cases would clearly be of the greatest interest in order to pinpoint the nature of the connective tissue deficiency and to note also whether the venous plexuses fail to develop.

Treatment of Uterine Incontinence. The most widely accepted method which is successful in about 75% of cases, according to Garry M.M. et al (1970), is the insertion of a non-absorbable encircling suture (Shirodka) taking four bites as high up the cervix as possible in each quadrant. This can then be removed at 36 weeks when all risk of abortion or prematurity is over.

Electrical Treatment of Incontinence (Urinary and Faecal)

This is fully reviewed by Duthie (1969) who reveals its pitfalls and possibilities. This method began as a treatment for urinary continence and then, as its effect on faecal continence was noted, many ingenious efforts have been made to harness it as a cure for this condition.

Caldwell (1967) described how astonished John Hunter was when he dissected out the electric organs of fish to find the number of nerves needed to supply such an organ.
Subsequent investigators have found these organs to be formed from modified muscle developed from primitive myotomes which can discharge considerable current. For example in air a large eel can produce 3 millisec pulses of 600 volts.
Applying this principle in reverse, current passed into sphincteric muscles, which have been inadequate for periods of 11 and 23 years, produced a remarkable return of contractile function.

Flannery (1968), as noted earlier, showed that stimulation of the levator caused contraction of the whole pelvic floor. This fits in with its unit behaviour in a number of pelvic reflexes already mentioned.

Difficult to understand is the report from Moore and Schofield (1967) that maximal contraction of 'all pelvic floor muscles under anaesthetic' may improve urinary stress incontinence. Stimulation of this type was given in the region of the perineal body. Stimulus intensity was increased until all the voluntary musculature of the pelvic floor gave a maximal contraction. Four to six such tetanic contractions were produced in each patient. They claimed seven cures and four improvements with this method in a series of 17 patients. For such a method to work unusual properties in the muscles

/stimulated ....

stimulated must be postulated.

Fischer and Von der Mosel (1968), following the lead of Hopkinson and Lightwood (1967), have employed anal plugs in a different clinical circumstance.

Patients, who were incontinent because they were unconscious after neurosurgical procedures, were controlled by an hour-glass shaped plug in the anal canal. This stimulated the musculature. At 24 hourly intervals removal of the plugs was followed promptly by evacuation.

The mucosa was unharmed by this method which could prove a useful nursing aid.

Synopsis of Treatment of Incontinence

Efforts to restore faecal and urinary continence may be summarised as follows:

1. Pelvic exercises, which must also be employed to supplement all treatments.
2. Electrical treatment.

   a) Trial and error implants and anal plugs designed to stimulate dormant but still competent striated pelvic floor musculature.

   b) Electronic implants as described by Scott et al (1965) in the wall of the bladder especially. These are designed to provoke smooth muscle contraction without radiation of influence to afferent or efferent somatic nerve fibres. Again this depends on trial and error. This method may be extended in time to encourage a sluggish colon to retain its contents or empty itself.

   c) Alexander and Rowan (1968) found that direct stimulation of pudendal nerves in dogs effectively prevented escape of urine from the bladder. On this basis they developed radio implants, which deliver a continuous electrical stimulus to the pudendal nerves, in humans. In ten female and four male patients, substantial benefit accrued in 64% of them with this treatment. This method can exert control over the whole pelvic floor in a positive way and its advantages are that

      1. the pudendal nerves are reasonably accessible
      2. spread to obturator nerve and adductor spasm, as may occur when an implant is placed in pubo-coccygeus is avoided

/3. ....

3. Operative measures

a) Those designed to (i) reconstitute vital ano-rectal and posterior urethro-vesical angles, (ii) improve anchoring of the viscera with restoration of a measure of sphincteric control appear to hold out most hope of functional improvement.

b) As a final resort colostomy and urinary diversion provide a considerable measure of relief when all treatments directed at the pelvic floor and its viscera have failed.

An appreciation of the essential oneness of the pelvic floor muscles and full understanding of the reflex and voluntary dynamic interactions between them and the pelvic viscera holds the key to future success in prophylaxis and treatment of their disorders.

PART 3.

NERVOUS CONTROL

a) Reflexes

These are:

viscero-visceral
viscero-somatic
somato-somatic and
somato-visceral.

They depend on the fact that the second, third and fourth sacral segments of the cord are largely responsible for the innervation of the pelvic viscera and of the skin and muscles of the perineum and pelvic floor. Unfortunately some reflexes fit partly into one and partly into another category as I shall show.

1. Viscero-visceral

a) Intrinsic

i) intestino-intestinal reflexes abound for example the relaxation of the internal sphincter which accompanies rectal distension

ii) bladder to bladder - see bladder reflexes.

Extrinsic viscero-visceral reflexes, involving afferents from pelvic viscera to the sacral cord and back via the nervi erigentes, are well documented.

Reviewed repeatedly since their discovery by Barrington (1921, 1925,

/1931, ...

19

1931, 1941) are reflexes having a long arc through the brainstem.

b) Irradiation of impulses between viscera based on their common innervation and proximity forms the basis of

i) increased activity of the bladder when the bowel is overactive

ii) contraction of the empty rectum when the bladder is emptied, this was noted first by Denny Brown in 1935.

iii) activity in the reproductive tract causing disturbances of bowel habit

iv) although not an absolute corrollary Jeffcoate's (1969) observation that 'irritable colon syndrome' cases are quite commonly misdiagnosed as having a gynaecological cause may be pertinent

v) the reproductive tract, especially on a mechanical basis, can profoundly influence the activity of the bladder, whether reciprocity exists here is less certain.

2. Viscero-somatic

These are of profound importance in the co-ordinated functioning of the pelvic floor and viscera. Evidence accumulated by Bors (1957) shows that viscero-somatic reflexes may arise due to mucosal stimuli or due to proprioceptive ones involving stretch receptors - he calls the former extero-ceptive reflexes but this is confusing when applied to the linings of viscera. The terms interoceptive or enteroceptive cover both mucosal and proprioceptive responses in viscera so do not constitute useful alternatives. The recto and cysto-sphincteric reflexes are the classic examples of viscero-somatic reflexes and occur even after transection of the cord above L3. Thus electrical silence reigns most of the time during both defaecation and micturition in the sphincters and musculature of the pelvic floor.

Kuru's pelvico-abdomino-perineal reflex however recruits neurones at brainstem level.

Bladder Reflexes

a) Reflexes which maintain continence and promote storage of urine were elaborated over a period of 20 years by Barrington and clarified by Kuru among others.

/1. ....

1) Impulses from tension receptors in the bladder wall reach

i) the sacral cord and inhibit autonomic cells whose axons cause vesical contraction

ii) the hind-brain, as will be described in the next section, to inhibit cells whose axons cause vesical contraction.

2) From tension receptors in the bladder wall impulses pass to somatic cells innervating the external urethral sphincter so increasing its tone as the bladder distends.
These anterior horn cells receive facilitatory input, as will be seen, from pontine cells.

3) A guarding reflex whereby the external urethral sphincter contracts when the proximal urethra is distended with urine (Garry 1968). Very similar is this to the external anal sphincter contraction which occurs with rectal distension and internal sphincter relaxation.

b) Initiation of micturition depends on the D.O.P. at which the detrusor contracts and the sphincters relax

1) Impulses from the bladder and urethra reach

i) the spinal cord and result in vesical contraction and urethral relaxation

ii) the brainstem where inhibition of vesico-relaxer cells results in vesical contraction and neurones in this region also co-ordinate the discharge to lower motorneurones operative in Kuru's reflex.

c) Reflexes concerned with the continuation of micturition are mediated by:

1) The detrusor centre sited in the pons and first described by Barrington in 1925.

2) Mid-brain neurones which inhibit relaxation through their pathways to vesico-relaxer cells in the pons and medulla

3) Spinal circuits including a detrusor-detrusor one provoked by contraction of bladder muscle and an urethra detrusor one whereby contraction is sustained as long as fluid flows through the urethra.

/Analogous ....

Analogous the latter is to the bowel contractions provoked by the passage of a bolus through the anal canal.

d) Even cessation of micturition is accompanied by a complicated series of reflexes including elevation of the pelvic floor and closure of the sphincters.

It seems highly probable that reflexes, analogous to those which regulate bladder function, pertain with regard to the filling and emptying of the terminal bowel. A basis for some of these is suggested by the motility, pressure, electromyographic and radiological studies noted in Section IV, and further evidence in favour of such an analogy is given by the similarity of pathways and responses in the lower brainstem which are considered in the next part.

Viscero-somatic reflexes are operative also in pathological conditions such as strangury in which facilitation of the detrusor muscle is accompanied by spasm of pelvic floor musculature.

3. Somato-somatic

1) Stimulation of the skin and mucosal surfaces of the perineum produces contraction of the superficial and deep pouch musculature and of the external anal sphincter. This has been known at least since 1884, when according to Hiller (1931), Baker Brown attributed anal fissure in some cases to onanism, when he found that stimulation of the clitoris gave rise to strong contraction of the anal sphincter under chloroform anaesthesia. Perianal and bulbo-spongiosus reflexes are routinely checked by neurologists.

2) A guarding reflex, when the anal canal is penetrated, due to stimulation of sensory endings in mucosa and submucosa and proprioceptive receptors in the muscles produces vigorous contraction of the pelvic floor muscle as described by Porter (1962).

3) On the other hand passage of a bolus through the anal canal, or urine flowing through the urethra, enhance inhibition of the pelvic floor muscles and, as noted several times, prolonged straining produces relaxation of the inhibited pelvic floor musculatures.

4) The 'closing' reflex, which occurs at the end of defaecation and micturition, is probably mainly a somatic reaction due to release from

/stretch ....

stretch stimulating receptors of an 'off' type. This produces a burst of activity which causes the pelvic floor to rebound and reconstitute its sphincters and angles. It may also have a viscero-somatic component as well.

5) Tonic Reflexes - Muscle spindles have been found in the muscles of the pelvic floor (Walls, 1958).

By their proprioceptive feed-back action they help maintain a constant electrical discharge from the external sphincters and levatores with their resultant tone. Porter (1962) remarks that it has been postulated that the reflex tone of the pelvic floor muscles is due to a stretch reflex. However, an increase in the stretch stimulus to the receptors in the muscles results eventually in a reflex relaxation. This seems to me akin to the inhibitory effect exerted by Golgi tendon organs, when a stretch stimulus is prolonged beyond a certain critical level, so that further contraction might lead to overstretching and rupture of the muscle concerned. It is clearly mandatory that the contents of the pelvic viscera be not dammed up indefinitely. These inhibitory afferents must allow for relaxation as a safety device. Transection of the spinal cord below L4, according to Schuster (1968), but not above it, is said to abolish tonic discharge and it is also said to disappear after transection of S2, which is the afferent pathway for maintaining tonic activity.

Phasic Reflexes - These result in transient increases in contraction in response to emergencies. They may arise on a viscero-somatic (e.g. rectal distension with external sphincter transitory contraction) or somato-somatic basis (e.g. rises in intra-abdominal pressure or following stimuli applied to perineal skin or anal mucosa).

Phasic reflexes persist if S2 posterior nerve roots are sectioned. Bilateral section of the posterior roots of S3 abolishes both tonic and phasic reflexes.

Discussion

Tonic and Phasic reflexes are not abolished on either side of the external anal sphincter if one pudendal nerve is cut and this must indicate I think:

a) the considerable length of individual annular fibres

/b) ....

b) that annular fibres must be of both red 'slow' Type I and white 'fast' Type II varieties.

Further corroboration of the above is given by the fact that unilateral pudendal nerve stimulation produces contraction of the whole circumference of the external anal sphincter and presumably of the superficial and deep pouch muscles supplied by this nerve as well. Conversely, to reduce activity in these muscles, bilateral pudendal neurectomies are needed.

4. Somato-Visceral

A bolus passing through the anal canal excites activity in the proximal colon. Abnormal sensitivity in this respect may lead to a further call to stool half an hour or so after defaecation.

It is well known that cold air impinging on perineal skin invokes micturition in an infant when its nappy is removed.

Somato-visceral reflexes are the reason for stimulation of trigger zones inducing mass reflex in paraplegics.

Viscero-autonomic responses

This name seems most appropriate for this category of response although I have not seen it used.

a) In normal persons, occasionally, after relief from vesical and to a lesser extent rectal distension, shivering may occur as noted by Griffiths (1933) and a slight gush of tears in the eyes may appear.

b) In paraplegics with automatic cord bowel and bladder function when the rectum is distended viscero-autonomic responses occur as noted by Truelove (1966). These include sweating, pilo-erection, rises in blood pressure and subjective feelings of heat and fullness in the head - they are due to reflex vasoconstriction in the paralysed parts of the body.

c) The diarrhoea which may accompany acute fear Nasset (1968) believes is due to parasympathetic overaction antagonising the effect of an outpouring of adrenaline.

b) Central Connections

Considerable research has been devoted to solving the complexities of the central connections of the autonomic fibres which supply the pelvic

/viscera. ....

viscera. Evidence has been amassed which shows that, at all levels of the neuraxis, there are closely related and inter-connected neurones, which exert facilitatory and inhibitory effects on both bladder and bowel. The description by Hiatt and Santulli (1962) of the ano-rectum as a primitive evacuating mechanism with none of the finesse of the urinary system can be summarily dismissed.

It is of some interest that no current neuro-anatomical text, which I have consulted, gives any concise picture of the ascending and descending pathways concerned with contraction and relaxation of the terminal bowel and bladder or of erection. Nor are the sites and connections between neurones, rostral to the cord, whose stimulation provokes these activities, described.

Spinal Cord

Grey Matter

The autonomic neurones immediately concerned with micturition, defaecation, erection and perhaps parturition are all located in the intermediolateral extension of the grey matter, which is located laterally at the base of the posterior horn in the sacral cord and also forms a prominent feature of the thoracic and upper lumbar cord. Those with motor function lie anterior to cells with a sensory connotation.

Parasympathetic cells are located essentially in the third and fourth sacral segments, whereas the sympathetic cells under consideration, are found in the lower thoracic and upper lumbar regions.

A sacral 'viscero-motor' centre is postulated and a lumbar 'ejaculatory' one.

Somatic cells with motor functions, comprising alpha and gamma motorneurones, are found in the anterior horn of sacral segments. Chromatolysis of these cells in the third and fourth sacral segments was noted by Kambe (1944) quoted by Kuru (1965) after abdomino-perineal rectal resection. This corroborated the belief established on clinical grounds, that motor centres for the levator and external sphincter are located in this region although the sparing of S2 pudendal fibres is difficult to explain. I was not able to follow up this reference.

Cells with a sensory connotation are found in the posterior horn of grey and these cells, as well as adjacent viscero-sensory ones,

/receive ....

receive sensory input including that set up by painful stimuli from

terminal bowel

neck of bladder

prostate

cervix of uterus (White and Sweet, 1943, 1955)

although Routledge and Elliot (1962) do not fully agree with their findings.

White Matter

The pathways implicated in micturition will be described as elucidated by Barrington (1933, cat), Nathan and Smith (1950, 1953, humans), Kerr and Alexander (1964, cats, monkeys) and Kuru (1965, dogs). There seems every reason to believe that comparable pathways exist which convey impulses concerned with ano-rectal function.

Like all sensory fibres the central processes from the posterior nerve roote bifurcate when they enter the spinal cord. This allows for ascending and descending connections with segments above and below, and, via collaterals of these fibres, influences can reach both sides of the cord at many levels. Opportunity for effective feed-back circuits between the pelvic viscera and the spinal cord, mediating a number of the reflexes described earlier, can thus be envisaged.

Ascending Pathways

a) Fibres, which convey impulses set up by pain and temperature, as well as sense of bladder fullness and desire to void, arise in 'visceral sensory' neurones, sited posterior to sulcus limitans, in the intermedio-lateral grey of sacral, lumbar and thoracic segments. They mainly cross in man and are then found in the antero-lateral columns of white matter closely related to the spino-thalamic tracts. They end, according to Kuru (1965), mainly in the reticular formation of the medulla oblongata:

i) in cells related to 9th and 10th nerve nuclei, especially those adjacent to the nucleus of the solitary tract, (para-solitary nucleus)

ii) ventral and lateral reticular formation

iii) cells at the rostral tip of the gracile nucleus close to the ala cinerea (para-alar).

/The ....

The fibres, which end in (iii), were confused with spino-vestibular fibres because the para-alar nucleus lies in the lateral recess of the 4th ventricle in close proximity to vestibular neurones.

b) Fibres, which are carrying impulses relating to passive distension of the bladder, travel via S3 and 4 posterior nerve roots and then pass uninterrupted in the posterior columns to reach the para-alar nucleus of the medullary reticular formation. They thus meet up with afferents, which have traversed the antero-lateral columns.

These findings are not in accord with White (1943), who believed that all impulses related to filling, and therefore stretch of the bladder and rectum, were carried in the posterior columns. It may be that sense of fullness is conveyed by both routes and impulses in the antero-lateral column depend partly on somatic afferents from the peritoneum overlying the bladder (Crosby, 1962).

Rhombencephalon

Medulla Oblongata

Grey Matter. - Kuru and Hukaya (1954) using narcotized, carotid-ligated and decerebellate dogs, stimulated various parts of the floor of the fourth ventricle with a fine electrode. At the same time they recorded changes in the tone of the bladder and rectum. After each stimulation the area stimulated was destroyed so that serial sections could locate the sites where contraction or relaxation of the viscera was provoked.

In general, each successful stimulation was followed, either by a single contraction or by a relaxation with consecutive contraction. In most instances reactions of both bladder and rectum, similar in type, appeared simultaneously. Contraction was elicited most easily from the region of the juxtasolitary nucleus and lateral reticular formation, whereas relaxation occurred when the dorso-medial reticular neurones were stimulated. This last finding would be in keeping with the tendency of lower, medial, medullary reticular neurones to produce inhibition. It has, of course, been conclusively proved that destruction of this zone abolishes decerebrate rigidity.

A discrepancy between the text and the diagrams in the 1954 article is very curious. Areas in the lower part of the floor of the fourth

/ventricle ....

ventricle, which on stimulation elicit conspicuous contraction, are shown near, or immediately adjacent to the mid-line, whereas the areas, whose stimulation elicited conspicuous relaxation, are shown in the lateral medullary reticular formation. Ruch (1960), who reproduces this diagram of Kuru and Hukaya, questions whether cells in the medulla are in fact involved or whether stimulation only affected fibres 'en passage' but does not comment on the discrepancy.

Because Kuru's 1965 statements and illustrations appear more likely they are reproduced here.
These medullary neurones receive input from the pelvic viscera and, because they are reciprocally connected, play a role in allowing the filling and emptying of the bladder. Further, they can recruit adjacent reticular neurones, whose discharge leads to excitation of the lower motorneurones, whose axons pass to muscles participating in the pelvico-abdomino-perineal reflex of Kuru referred to earlier. Proof of this is furnished by the fact that a discrete lesion in the medulla can abolish this reflex.

Hatcher and Weiss in 1924 found that destruction of the sensory nucleus of the vagus in the ala cinerea rendered creatures able to vomit, unable to do so. As they remarked on the co-ordination involved in this act they predicted the role of reticular formation cells in descending systems in a most perceptive way. They concluded that the sensory nucleus of the vagus was essential for vomiting but that associated cells must co-ordinate all the lower motorneurones implicated in the affair. Very close to their vomiting centre, application of 0.016 mg. of picrotoxin, within one minute produced diarrhoea with faecal discharge containing blood-stained mucus due to violent peristalsis. 1/16th of this dose caused defaecation in another experimert . A number of other substances also produced diarrhoea on application including nicotine and quinine.
Frequency of urination, accompanied by hiccough, followed the application of pilocarpine to the same area. This drug, when given intravenously, produces increased urination. Their results proved that a defaecation centre existed in the floor of the fourth ventricle.

The relationship of these centres to chemo-receptor trigger zones,

/proven ....

proven to exist in the floor of the fourth ventricle, has yet to be established. It is probably no coincidence that these cells lie in close proximity to the 'respiratory centres'. This may account for the fact that defaecation does not begin until after the infant has drawn its first breath.

White matter - Ascending fibres in the spinal lemniscus (fused anterior and lateral spino-thalamic tracts) and from the juxtasolitary and para-alar nuclei pass through the pons and mid-brain giving collaterals to reticular neurones in each region, particularly to those whose stimulation produces contraction or relaxation of the bladder. They reach the thalamus and hypothalamus, via the former reaching the neo-cortex, and, via the latter neo-cortex and various cell stations, which with the hypothalamus, belong to the limbic system. One concern of this system is the regulation of the visceral and emotional aspects of behaviour.

Descending fibres will be considered later.

Pons

1) Grey Matter

In 1921 Barrington declared that reflex arcs, which lead to strong and sustained bladder contraction, are located above the spinal cord. In 1925 he described cells in the rostral pons, bilateral destruction of which, led to permanent inability to empty the bladder. They are necessary therefore for the continuation of micturition. Kuru (1965) sites these cells in the dorso-lateral reticular formation of the rostral pons. This nucleus is acknowledged by Ruch (1960) as Barrington's detrusor nucleus, which has a powerful facilitatory effect on micturition. Stimulation of these cells produces detrusor contraction co-ordinated with external urethral sphincter relaxation.

2) Caudal and ventral to these cells is another group of co-ordinating reticular neurones, whose stimulation produces:

a) Relaxation of the detrusor

b) Contraction of the external urethral sphincter

Barrington also described these neurones in 1925 and noted that bilateral destruction, although not interfering with voiding, resulted in a loss of the sense of the desire to void. This suggests that ascending pathways

/traverse ....

traverse this nucleus.

White Matter

Ascending fibres are the same as those noted in the medulla. Descending fibres will be considered later.

Mesencephalon

Grey Matter

Reticular neurones, whose stimulation causes detrusor contraction, related to the superior colliculus and adjacent tegmentum have been reported. Vesico-relaxer reticular neurones are apparently found at inter-collicular, inferior collicular and adjacent tegmental levels (Koyama et al quoted by Kuru (1965) and Chin Tang (1955)). Bilateral destruction of dorso-medial and mid-brain tegmentum in rats results in haematuria (George et al, quoted by Kuru). The mid-brain centres are doubtless valuable in helping to co-ordinate the various postural adjustments involved in both micturition and defaecation. They receive important afferents from the limbic system to be described presently.

White Matter

Ascending fibres are similar to those traversing the pons. Descending fibres will be considered later.

Suprasegmental

a) Limbic System

1. Hypothalamus

When one considers that hypothalamic functions include

a) Regulation of all bodily rhythmic cycles
b) Control of the internal environment via
    i) autonomic pathways
    ii) Biochemical homeostatic mechanisms
c) Control of much of the endocrine system

and

d) Translation of emotions aroused by cortical regions into fitting autonomic, endocrine and motor responses

it is not surprising that results of stimulation and ablation in this restricted area are seldom unequivocal.

Olds (1967) stated that the region is a junction box between two

/major ....

major pathways, the medial forebrain bundle entering and the great paraventricular system leaving. Stimulation of incoming fibres, in his opinion, will induce animals to work to turn the system on, and stimulation of outgoing fibres will induce animals to work to turn it off. Stimulation of the hypothalamus itself will give mixed results. This ingenious theory does not take account of the fact that fibres both enter, leave, and traverse the hypothalamus via the medial forebrain bundle, or that paraventricular fibres pass up to the thalamus and cortex and down to the hypophysis, as well as downstream en route autonomic cell stations at various levels.

Perhaps Brodal (1969) is nearer the mark when he states that hypothalamic 'centres' represent 'areas in the nervous system, which are essential for the proper performance of certain functions'.

Stimulation within the hypothalamus has produced inhibition of peristalsis in many species including the cat (Kabat et al (1935) and Ranson et al (1935)) and occasionally facilitation of visceral activity (Truex and Carpenter, (1969)). In man, changes in bowel motility related to emotions have been noted earlier. These presumably are mediated through the hypothalamus.

Contraction of the bladder has also frequently been recorded during stimulation studies of the hypothalamus. Outstanding is the work of Enoch and Kerr (1967), who have found that stimulation of neurones in the dorso-medial and posterior hypothalamus of cats, produces both vesical contraction (parasympathetic) and vasoconstriction (sympathetic). By degeneration studies a medial pathway was traced, which passed (mainly via a relay in the periaqueductal grey) to the tegmentum of the upper mid-brain. The rest reached the tectum at superior collicular level.

2. Septal area

The septal nuclei form a nodal area enjoying reciprocal relationships with the hypothalamus, amygdala and hippocampus as well as with limbic and neo-cortex.

The septal area has been shown by many workers to influence behavioural responses as well as certain visceral and endocrine activities.

Kabat et al (1935) were the first to remark contraction of the bladder

/when ....

when septal nuclei (and adjacent pre-optic cells and cells related to the anterior commissure) were stimulated.

Of relevance here are the findings of Covian (1965) in rabbits. He postulated two antagonistic systems intermingled in the septal area which both acted on blood pressure. One induced hypotension and the other hypertension. Maclean (1960), a pioneer in the limbic field given to memorable, though somewhat sweeping generalizations, with co-workers made the interesting discovery that some of the limbic structures closely allied to the septum may exert localized circulatory effects. They found that this region played a special part in the preservation of the species. Grooming, enhanced pleasure and manifestations of sexual activity appeared in rats and cats when it was stimulated. In the squirrel monkey, a small primate, stimulation of septal nuclei produced penile erection with localised circulatory effects and this could be evoked at points in front of the anterior commissure into the pre-optic region and then caudally through the hypothalamus along the course of the medial forebrain bundle. The response was best elicited by different frequencies in the various sites, which may be due to nuclear as opposed to fibre, stimulation. To reach a point where stimulation produced a positive response the electrode commonly triggered off micturition. The only autonomic change of consistent nature associated with erection was micturition, which might or might not, accompany the response.

The above studies tie in very well with the work of Enoch and Kerr (1967) who, in addition to the medial hypothalamic pathway arising in the hypothalamus and mediating bladder contraction and vasoconstriction mentioned above also found a lateral pathway, which produced the same effects, and was contained within the medial forebrain bundle. This pathway is made up mainly of the axons of cells in the pre-optic, septal and other limbic structures (?e.g. amygdala). It ends in the tectum at superior collicular level and in the same upper tegmental region which receives the medial pathway.

From the tectum and tegmentum of the upper midbrain impulses are relayed downstream to lower midbrain, pontine and medullary reticular

/neurones ....

neurones controlling contraction and relaxation of the detrusor. How vasodilator impulses, which control the nervi erigentes, travel from the septum is as yet unknown.

3. Amygdala

Ursin and Kaada (1960) and Ursin (1964) and Gloor (1960) are among the many who have reported alterations in bladder tone, sexual activity, and flight and defence patterns induced by amygdaloid stimulation and ablation.

Stimulation of basi-lateral nuclei causes relaxation of the detrusor. This may be equated with the desire to micturate associated with feelings of fear (flight), also elicited by stimulation of the basi-lateral zone, and the absence of such desire associated with anger (defence), provoked by stimulation of cortico-medial amygdala.

Ursin and Kaada (1960) found that defaecation was provoked only when the anterior amygdaloid nuclei were stimulated.

b) Cerebellum

Evoked potentials can be recorded by bladder distension in the cerebellum and altered voiding habits can be induced by stimulation and ablation of the anterior lobe especially. This just adds to the evidence, which shows the cerebellum to be intimately linked, not only with somatic motor and sensory systems, but with visceral ones as well.

c) Telencephalon

Contraction and relaxation of the bladder have been reported from many areas in the cerebral cortex including sensori-motor cortex, gyrus cinguli, orbital gyrus and pyriform cortex. Increase and decrease in gastro-intestinal motility has been noted on stimulation of various parts of the limbic and sensori-motor cortex in animals and when the insula, borders of the Sylvian fissure, and gyrus cinguli are stimulated in man (Elliasson (1960)).
The work of Airapetyants and Sotnichenko, which has followed the teaching of Pavlov have established certain cortical regions in dogs which have a 'visceral analytic' function and receive interoceptive information. They speak of mechano-, chemo- and thermo-analysis and have shown that decortication completely abolishes the formation and analysis of visceral

/conditioned ....

conditioned reflexes. The cells which have this function are found in motor (area 4) and premotor (area 6) as well as in the limbic lobe. As I understand them these functions may be transferred to adjacent regions when the central part of the visceral cortex is damaged.

Nathan and Andrews (1964) collected a series of patients with lesions of the anterior frontal lobes, who had disturbances of micturition and defaecation. Their patients fell into four aetiological groups -

brain tumours

aneurisms

penetrating brain wounds

leucotomies

The lesions involved the 'antero-medial frontal lobe at the level of the genu of the corpus callosum and included the anterior part of the gyrus cinguli'. Incontinence of urine was striking in all cases and a significant proportion had disturbance of bowel habit. This included frank incontinence in a few. Their most dramatic case had a transfrontal wound with its posterior limit just posterior to the coronal suture. Following operation, to remove a bone fragment, this patient was totally incontinent of urine and faeces, being unaware even that the latter were passing. This case highlighted the gravity of a bilateral lesion. It is usually interpreted as having removed the para-central gyrus and upper precentral gyrus between the arm and the leg area (Crosby, 1962). Their findings accord well with those of Whitty (1955), who reported on vasomotor and visceral effects of anterior cingulectomy. In one case involuntary evacuation of bowel and bladder occurred during the operation and, in all cases, incontinence of urine for a few days post-operatively occurred. This was not a feature remarked in other neuro-surgical patients who were continent pre-operatively.

Ursin and Kaada (1960) reported defaecation on stimulation of the putamen and Lewin (1967) has invoked other extrapyramidal nuclei as playing a role in continence but I have not been able to obtain this reference.

Descending Pathways

Reticular neurones in the mid-brain influence those in the pons and those in the pons project to medullary reticular neurones. From the telencephalon and diencephalon fibres descend to influence the reticular brainstem 'centres' outlined above although many of these pathways have not yet been clearly

/defined ....

defined.

From reticular neurones of the brainstem reticulo-spinal tracts descend which, in addition to carrying extrapyramidal influences to lower motorneurones, reach the intermediolateral column of grey by way of the antero-lateral columns of white matter.

They are:

1) The lateral reticulo-spinal tracts, which arise from vesico-contractor neurones in the lateral medulla, rostral pons and midbrain, as well as from other reticular neurones.

These end in thoraco-lumbar and sacral autonomic connector neurones. In the sacral segments collaterals pass to the anterior horn cells.

2) Ventral reticulo-spinal tracts arise from medial reticular neurones of the medulla close to the hypoglossal nucleus. These convey inhibitory impulses to the sacral visceral centres, whence collaterals reach the sacral somatic anterior horn cells as well.

3) The medial reticulo-spinal tract, which carries mainly extra-pyramidal fibres, also contains fibres from the pontine 'centre' which produce relaxation of the detrusor and contraction of the external urethral sphincter. Stimulation of these fibres results in increased electromyographic activity in the external sphincter. Both crossed and uncrossed fibres are found in these tracts, whose exact location is still under review. Kerr and Alexander (1964) in a well considered study compared their findings in this respect with those of Foerster (1939), Nathan and Smith (1956) and Kuru (1959). They found vesico-motor (vasomotor and pilomotor) fibres superficially placed in the lateral column of white matter in the cervical region. In the thoracic region however, the vesico-motor fibres were all posterior to the denticulate ligament, a position assigned to them by Barrington in 1933. Clearly to reach the intermedio-lateral column they must move medially in lower thoracic, lumbar and sacral regions.

This study does not preclude the pathways postulated by Kuru (1965) and Crosby (1962) for descending fibres which exert control over the viscera.

Discussion

Multi-levelled feedback circuits, at which the nervous system excels, control micturition and erection and doubtless defaecation as well. Such a delicately balanced hierarchy can be compared with that which produces

/orderly ....

orderly and purposeful, rather than random movements, of skeletal muscles. It is seldom that brainstem lesions produce disturbances of these functions, because, bilateral lesions, sufficiently widespread to interfere with these nuclei and pathways, soon prove fatal.

SUMMARY AND PARTICULAR CONCLUSIONS

FASCIA

From dissection in human and a few sub-human species a new approach to the pelvic fascia of Man has been evolved.

The pelvic fascia is formed of three interdependent component parts which may be termed parietal, septal and visceral. These have been fully described and illustrated.

Parietal fascia forms the epimysial fascial sheaths of muscles. The layer of most significance is that which clothes the levator ani. This is termed the superior fascia of the levator. It is continuous round the medial free border of the muscle with the inferior fascia of the levator.

The superior fascia of the levator is attached:

a) to the brim of the true pelvis
b) to the peripheral septal layer along the white line of the pelvic fascia which extends from the back of the pubis along the antero-lateral inner pelvic wall to reach the ischial spine
c) to the pelvic viscera at their sites of penetration of the urogenital and pelvic diaphragms
d) via the above-mentioned continuation into the inferior fascia it, in turn, becomes continuous with the anal fascia which covers the external anal sphincter.

Septal

This is conveniently divided into:

1) a peripherally sited, extraperitoneal layer which is always medial to the parietal layer. It is continuous above with the extraperitoneal tissue of the abdominal ~~viscera~~ walls. Below it is

a) interrupted by its relation to the lateral margins of the bladder which organ it splits to enclose
b) attached along the white line of the pelvic fascia to the parietal layers

/c) ....

c) converges on the remaining pelvic viscera at their sites of penetration of the pelvic diaphragm.

In this connection condensations of the peripheral septal layers form most of the so-called 'ligaments' of the pelvis which are fully described in the text. In different subjects these vary in development very considerably.

2) transversely directed septa which connect with the peripherally sited layer. These are described.

Visceral

This is composed of the intrinsic fascial coat of the organ which varies in amount in relation to different parts of each viscus and may be minimal. Where the viscera traverse the pelvic floor the intrinsic coat is reinforced by:

a) Parietal and

b) Septal

accessions.

Pubic ligaments attach urethra, bladder and prostate to the pubic bone anteriorly and may provide a fulcrum for emptying of the bladder and upper urethra.

Summary of Functions of the Pelvic Fascia

1. Conveyance of vessels, nerves and ducts to and from the pelvic viscera.
2. Fat within the septal layers
   a) forms a non-compressible cushion for nerves and vessels and ducts
   b) buoys up the pregnant uterus.
3. Transversely directed septa may prevent spread of infection.
4. Because of the arrangements described above and the proven strength of fascia, the paramount function of the pelvic fascia and its true 'raison d'être' is:
5. Helping to bear the weight of the pelvic and some abdominal viscera. This weight bearing function includes:
   a) resisting rises in intra-abdominal pressure

/b) ....

b) standing in for pelvic musculature

c) welding and strengthening

d) supporting by the formation of condensations known as ligaments which are largely related to vessels and nerves. These in turn help fasten the parietal and septal layers to the bony pelvic walls.

Because parietal and septal layers help suspend the viscera as they leave the pelvis and, via the anal fascia, the external anal sphincter, as explained in the text, the underlying musculature of the pelvic floor has no need to assume a weight bearing function. The levator ani is therefore a thin resilient sheet, which with moderately developed 'cloacal' sphincteric musculature, is able to perform its unique functions with maximum efficiency.

MUSCLES

The pelvic floor muscles are described and illustrated. The following are emphasised:

1. The complex interwoven relationships of the levator ani muscle.
2. The form and relations of the pubo-recto-analis muscle.
3. The commingling of striated and smooth muscle in relation to
   a) the ano-rectal region
   b) the urethra
   c) the vaginal wall.
4. The extension of striated muscle above the uro-genital diaphragm.
5. The functions of the pelvic floor musculature as a whole and of its component parts.

   It is postulated that pelvic floor muscles form an astonishing complex which illustrate a number of principles embodied in muscles in other parts of the body.

   Thus a) Synergic co-ordination between muscle groups is apparent.

   b) Intermingled striated and smooth muscles act in harmony with one another; and

   c) Parts of the same muscle may have antagonistic functions.

/6. ....

6. The gross and microscopic innervation of these muscles is described. I believe that the key to the mysterious activity of the pelvic floor muscles lies in some, as yet undiscovered, fact about their nature. Can it be because they are a modified type of muscle, somewhere between cardiac, striated and smooth muscle, such as develop from primitive myotomes in the electric organs of fish? Or is it due to an intermingling of striated and smooth muscle on an unprecedented scale? This may arise from the pelvic viscera which spray smooth muscle into their environs as described.

   Some such explanation must account for their unique properties, which include:

   a) remarkable electrical activity including slow waves
   b) unusual innervation
   c) histochemical properties of singular type, and
   d) behaviour which fits them perfectly for their functional role in relation to the pelvic viscera which traverse them.

   This study is in the embryo stage but is of such promise that as noted earlier we intend now to find out more about the nature of these muscles and their nerve plexus.

VISCERA

Topics in relation to the viscera which appear to have a bearing on the integrity of the pelvic floor have been analysed. They are:

1. angles exhibited by these organs. The importance of the perineal body and the raphe in the formation of the ano-rectal angle has been emphasised.
2. anchoring mechanisms which include connective tissue and muscular elements
3. venous plexuses in the ano-rectum, cervix, urethra and uro-genital diaphragm
4. the gross and microscopic innervation of the viscera and related clinical data
5. the morphology and applied anatomy of the visceral walls

/including ....

including elastic tissue elements, and

6. the ways in which special tests of viscera and floor can be correlated to elucidate function and dysfunction.

In the final section the distortions of normal anatomy which cause failure of the pelvic viscera either

a) to remain wholly above the pelvic floor, or
b) contain their contents until expulsion is timely

are considered, first in general terms, and then in relation to the individual viscera.

In this field prevention is more than anywhere else better than cure and having been fitted with a superb mechanism it behoves us to do all in our power to preserve it. The value of pelvic exercises which exert their effect on the whole functional unit of the pelvic floor is emphasised.

Descent of viscera results from:

a) Loss of anchoring mechanisms
b) Inadequacy of striated muscle due to trauma or neurological deficit
c) Alterations of vital angles
d) Diminution of the support afforded by elastic tissue and by fat in the pelvis and ischio-rectal fossae.

Measures which

a) Preserve continence are divided into prophylactic and surgical categories and are outlined;
b) Promote continence are considered.

Certain operations, which depend on minimal disturbance of the connective tissue, muscular and neural elements described earlier, are warmly commended on anatomical grounds.

c) Restore continence are noted. These are operative and electrical - the latter seems to hold the most promise for the future.

Reflexes of all varieties between the viscera and pelvic floor are reconnoitred and their central connections are examined and certain clinical findings, which I believe are not common knowledge, have been correlated with anatomical and physiological ones.

/This ....

This thesis has attempted to fill a need for

a) A description of the pelvic fascia which accounts fully for its all-pervading presence in the pelvis and relates this to its functions.

b) An accurate account of the muscles, striated and smooth, based on their functions and stressing their interdependence and innervation. This need was most felt in relation to the levator ani, whose fascial coverings have from antiquity, obscured its true attachments and relationships.

c) A statement of analogies between the mechanisms maintaining the integrity of the pelvic floor and terminal viscera based on anatomy, histology and special investigations.

d) Explanations of the rationale of certain procedures.

e) Suggestions based on a correlative study which, hopefully, may add more conviction to attempts to promote and preserve continence.

GENERAL CONCLUSIONS

1. As technological advances increase, co-ordination between the basic sciences and special fields is more than ever needed. As Skandalakis and Gray (1969) have remarked, the information explosion has not 'contradicted the findings of gross anatomy nor have they reduced the physician's need to find his way about the body.' An appreciation of fundamental anatomical facts is still essential and the highly diagrammatic, conceptual schemes, which appear in some texts, may distort reality so effectively that little remains of that truth which Keats held so dear. A combination of gross dissection with magnification on preserved and unpreserved material, sections in various planes and histological studies compared critically with operative findings and functional and histochemical tests should lead logically to a true three dimensional picture of the structure and function of these tissues and their vagaries. Each investigation alone is fallible. It is the function of the anatomist to provide only information on which the surgeon can rely implicitly and, when boundaries are not clear-cut, or variations preclude generalisations, these facts must be declared.

2. The pelvic floor is a difficult region to unravel because of:
   a) the interlacing of striated and smooth muscle
   b) the interweaving of connective tissue and muscular elements; and
   c) the complicated venous networks which infiltrate between tissue planes.

The purpose of this interlocking is clearly to produce a functional unit of great strength and efficiency, which can counteract the tendency of rises in intra-abdominal pressure, combined with gravity, to evert the viscera. In addition each viscus has its own strategically placed angles and sealing devices.

/3. ....

Footnote: Skandakis, J.E. Gray, S.W. 1969 The very unpopular Science Surg:Gynec: & Obstet: Vol. 128 No. 2. P. 350.

3. The exact attachments and relations of all parts of the levatores ani have been described and illustrated and the ways in which these muscles

a) help maintain important angles and increase urethral and rectal resistance

b) become attached to vaginal and rectal walls

c) become inseparably blended with the external anal sphincter

have been outlined.

The importance of the 'sling complex' in the ano-rectal ring has been stressed and the functions attributed to the various parts of the muscle have been described and correlated with radiological, electrical and pressure studies.

4. There is abundant evidence that the pelvic floor of man develops as a highly specialised, integrated musculo-fascial region which

a) helps to regulate intra-abdominal pressure

b) prevents descent or protrusion of viscera

c) plays a major role in the control of continence

d) facilitates expulsion of the contents of the pelvic viscera.

The idea that the pelvic floor is simply a transmogrified tail moving apparatus cannot be upheld when comparative findings are analysed. These findings lend strong support to the contention that, although the viscera have considerable freedom of movement within the pelvis, their caudal regions are anchored to the pelvic walls by fascia and muscle. The pelvic fascia, by relieving the strain on the relatively slender muscles, allows them full rein for their manifold reciprocal functions. In addition the pelvic fascia conveys all vessels, nerves and ducts related to the viscera and its fatty component may have a buoying and protective function as well.

5. The morphology of the pelvic floor in man is one manifestation of his adaptation to the upright posture. Thus major changes are:

/a) ....

a) The development of septal layers of fascia and the anchorage of the peripheral layer along the white line of the pelvic fascia to the parietal layer and so to the pelvic brim antero-laterally and directly to the sacrum posteriorly.

b) The increase in the strength of the parietal layers and their extension, by continuity, into the perineum where they help to suspend the anal canal and its surrounding musculature.

c) The breakdown in boundaries between some of the muscles so that functional co-operation can best be achieved.

Minor adaptations of interest are the development of:

a) the arcus tendineus of the levator ani in many instances; and

b) the development of the folds of Houston.

6. This study has confirmed the considerable range of variations, which the pelvic floor exhibits, based perhaps on the divergent patterns shown by the catarrhine monkeys on the one hand and the anthropoid apes on the other. Because of these variations it is suggested that the role of striated and smooth muscle in sphincteric control varies from person to person. This suggestion is strongly supported by physiological and clinical impressions as noted in Sections II and V

7. Presence of a Nerve Plexus in the Pelvic Floor. The unusual innervation of the sphincteric musculature of the ano-rectum is remarked. The annular sphincteric form of the muscle could account for the absence of a motor point. No explanation however is apparent for the plexus formation, numerous fine fibres and fibres of decreasing diameter noted, except that, in some way the musculature, whose properties are unique, is itself of a type which has evolved to meet the challenge of the delicate and specialised functions assigned to it. The muscles of the pelvic floor must have special properties, not only to perform the functions already listed, but also to enable them to recover after the merciless stretching

/imposed ....

imposed on them by parturition. To this end a nerve network of generous proportions would confer obvious advantages.

Undoubtedly some of these fine fibres are autonomic. The origin of sympathetic fibres, which accompany somatic nerves and blood vessels, is easily explained. The origin of parasympathetic fibres may be from the nervi erigentes as postulated on the basis of findings in the baboon, chimpanzee and man.

Neural feed-back circuits between the viscera, between viscera and the pelvic floor and between both these regions and the neuraxis have been discussed and their significance has been stressed.

8. The pelvic floor and the viscera which traverse it form a dynamic, functional unit of considerable complexity whose efficiency depends on a number of factors. Of these perhaps the most important is the remarkable and rich innervation of the area which endows it with exquisite sensitivity and unceasing diligence.

APPENDIX

TABLE I - Embryonic Material

C SERIES

No.	Photos.	CR mm	Sex	Procedure
1		10 mm	M	Examined externally Unsuitable
2		10 mm	M	Unsuitable
3		30 mm	M	Histology failed
4	2.42 and 2.43	30 mm	F	Coronal histology
5		35 mm	M	Histology failed
6	2.60 and 2.61	30 mm	Sagittal no gonad found	Histology

TABLE II - Foetal Material

A SERIES

No.	Photos	Section	CR c.m	CH cm	Wt. Gm	Sex	Age
1	4.4	Sagittal	28	39	1,800	F	8 months
2		Sagittal	10	15	86	M	4 months
3		Transverse	8	13	32	M	4 months
4	Part of Fig. 1.16	Parasagittal	24	34	1,243	M	7 months
5		Parasagittal	21	31	915	F	6-7 months
6		Hemipelvectomy	28	39	1,702	F	8 months
7		Transverse	27	39	1,690	M	8 months
8		Parasagittal	17	27	315	F	5 months
9	Part of Fig. 1.16	Sagittal	14	22	318	F	5 months
10		Sagittal	15	24	310	F	5 months
11		Transverse	16	25	320	F	5 months

Histological sections of 11 are shown in Photos. 1.21, 2.19, 2.20, 2.33, 2.51, 2.70, 2.72-2.80, 2.82, 2.83, 4.10, 4.11, 4.18, 4.22, 4.23 and 4.25

B SERIES

No.	Photo.	C.R cm.	CH cm.	Wt. Gm.	Sex	Age
1	4.6	26	36	1,282	M	7 months

Specimen mislaid.

Photographed for me by Prof. Romanes, Department of Anatomy in Edinburgh.

2. Parasagittal 14 week old female foetus. Photographs 2.10, 2.59 and 4.2.

3. Transverse 7 month old female twin. Photographs 2.52, 2.53, 2.54 and 2.55

E SERIES

No.	Section	CR cm.	CH cm.	Wt.Gm.	Sex	Age
1	Coronal	18.5	29	502	F	5-6 months
2	P/S	22.5	31	785	F	6-7 months
3	P/S	19.5	28	620	F	6 months
4	Coronal	20	29	636	F	6 months
5	Coronal	7	10	14	F	3 months
6	Transverse	9	15	55	M	4 months

F SERIES

No.	Photo.	Section	CR cm.	CH cm.	Wt. Gm.	Sex	Age
1		P/S	15	23	300	M	5 months
2		Coronal P/s	21	32	660	M	6-7 months
3		Transverse	5.5	8	12	F	3 months
4		Coronal	25	36	1,234	M	7-8 months
5		Transverse	9.5	13	45	M	4 months
6	Fig.2.65	Perineal dissection	27	36	1,268	M	7 months

In addition to the Anatomy Departments at Aberdeen and Cambridge I examined histological preparations of 26 pelves in stages of development from 28-230 mm at various levels, stained by different methods and cut in transverse, sagittal and coronal planes.

TABLE III - Full term infants, neonates and infants up to the age of 3 years.

D SERIES

No.	Photos.		Age	CR	Wt. in G.	Sex
1	2.40, 2.41	Whole	10 lunar months	36	4,232	F
2	Plate 2.50	Coronal	10 lunar months	35	4,012	F
3		Enucleation	10 lunar months	34	4,520	M
4		Enucleation	10 lunar months	33	3,200 G	M
5	Plate 2.25 based on	Sagittal	10 lunar months	32	2,800 G	F
6	1.20 & 1.22	Enucleation	10 lunar months	35	3,341 G	F
7	2.118 - 2.125 4.19 - 4.21	Postmortem Enucleation Histology	5 months		3,694	M
8		Partial Pelvectomy	3 years			F
9		Parasagittal	Neonate			M
10		Coronal	Neonate			F
11		Transverse	1 year old			F
12	2.58	Post-mortem	Neonate			F
13		Post-mortem	Neonate			M
14		Post-mortem	Neonate			M
15	1.33, 1.34, 2.15, 2.16, 2.17, 2.18, 2.24, 2.71 and 4.30	Post-mortem Transverse	Neonate Histology			F

TABLE IV - Adult Pelves

No.	Photos.	Sex	
1	2.22	M	Transverse
2		M	Transverse
3		M	Hemi-pelvectomy
4		M	Saggittal
5	1.28	F	Coronal
6	2.23 and 1.7	M	Transverse
7	1.26	M	Denonvilliers P/S Fatty septal layers
8	2.34 and 4.16	M	Partial Pelvectomy
9	1.29, Parts of Figs. 3.1 and 3.2	F	Transverse
10	Fig. 1.3, Photos. 1.15 and 1.27	M	Coronal

No.	Photos.	Sex	
11	Right half: 1.12, 1.13, 4.14, 4.15 and Left half: 2.26	M	P/S
12	2.3, 2.35, 2.31	M	Transverse
13		M	T/V.
14	2.21	M	Enucleation
15	1.8	M	Hemipelvectomy
16		F	Transverse
17		M	Partly enucleated
18		M	Hemipelvectomy
19	2.6, 2.7 & 2.8	M	Coronal/Sagittal
20	1.32, Part of Plate 2.69	M	Coronal
21	1.24	M	Transverse
22	2.36	M	Hemipelvectomy
23		M	Coronal Sections
24	Ant. half: 2.29 Post. half 1.19	F	Coronal
25	2.45 - Right half 4.17 - Left half	M	Sagittal
26	2.27, 2.28	M	Coronal
27	1.32	M	Parasagittal
28		M	Coronal
29	4.8	M	Transverse
30		M	Transverse
31	2.63	M	Enucleation
32	2.9	M	Coronal
33	2.48	M	Enucleation
34	2.81	M	Enucleation and Transverse
35		M	Transverse
36	2.32	F	Transverse
37		M	Hemipelvectomy
38		M	Hemipelvectomy
39	2.30 and 2.114	M	Enucleation
40		M	Parasagittal
41		M	Enucleation Recto-coccygeus
42		M	Hemipelvectomy
43		M	Parasaggittal
44	1.7 and 1.23	M	Parasagittal
45		M	Hemipelvectomy
46	2.11, 2.12, 2.13, 2.14 - Ant. half, 1.18 - Post. half	F	Coronal
47	1.14	M	Coronal
48		F	Parasagittal

No.	Photos.	Sex	
49		M	Hemipelvectomy
50		M	Parasagittal
51		M	Enucleation
52	4.1	M	Parasagittal
53		F	Coronal
54	Plate 1.6	F	Coronal
55	4.3 and 2.66, 2.67 and 2.68	F	Sagittal
56		M	Parasagittal
57	4.26, 4.27, 4.28	M	Post-mortem

In addition 79 dissected specimens were examined in Britain and on 6 of them further dissection was performed.
Photographs 2.56 and 2.57 are of a sagittaly sectioned male which was dissected at Newcastle.
Female pelvic arrangements were noted overseas to make up for the deficiency of such material here.

Certain points have been checked on additional specimens:

No.	Sex	
58	M	Sagittal
59	M	P/s
60	M	P/s
61	F	Hemipelvectomy
62	F	Hemipelvectomy
63	M	Hemipelvectomy
64	M	Hemipelvectomy
65	M	P/s
66	M	Hemipelvectomy
67	M	Hemipelvectomy
68	M	Hemipelvectomy
69	M	Hemipelvectomy
70	M	Hemipelvectomy
71	M	Hemipelvectomy
72	M	Hemipelvectomy
73	M	Hemipelvectomy
74	M	Sagittal
75	F	Sagittal
76	M	Hemipelvectomy
77	M	Hemipelvectomy
78	F	Hemipelvectomy
79	M	Coronal
80	M	Coronal
81	M	Hemipelvectomy
82	M	P/s
83	M	Hemipelvectomy

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