Biomechanics

and

Functional Anatomy

of

Human Female Genitalia

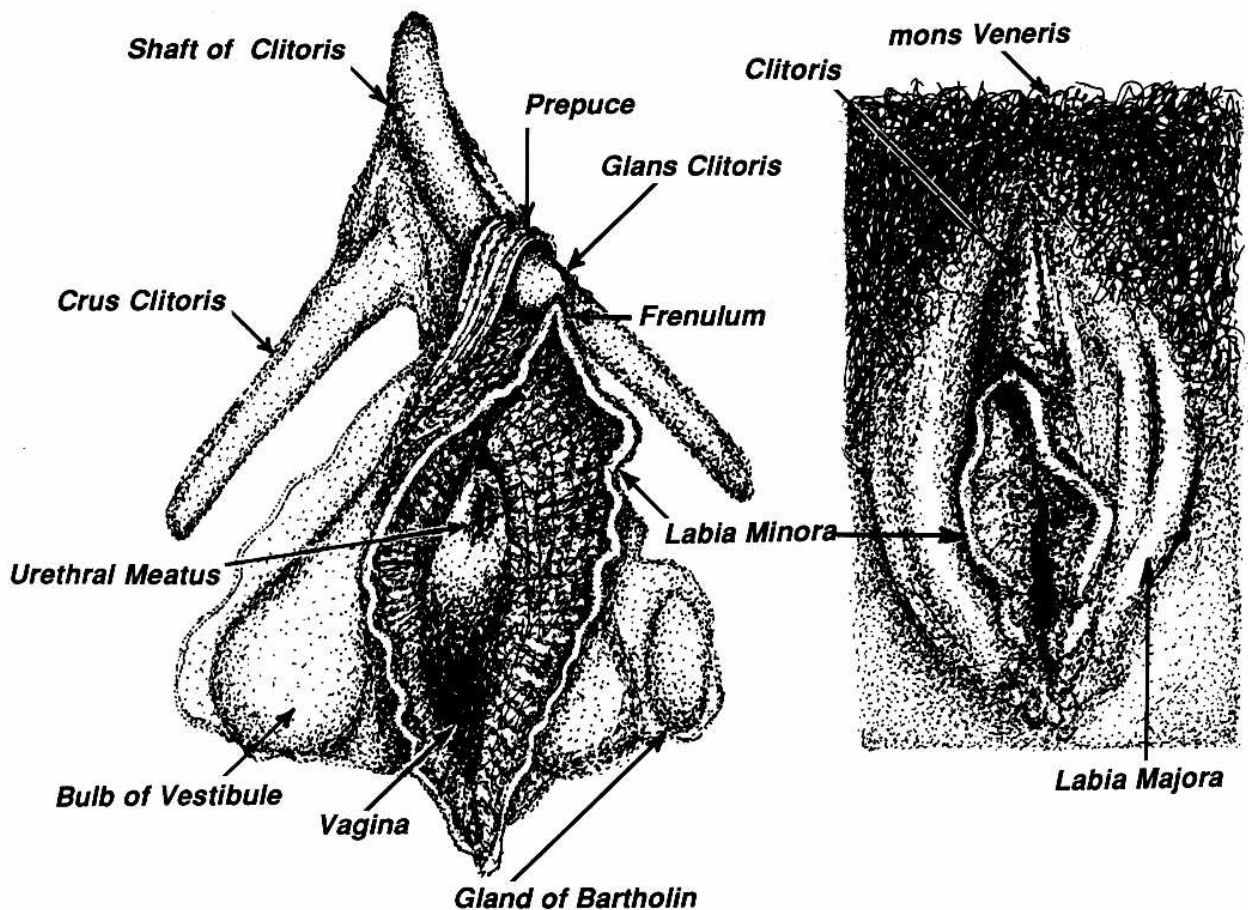For designers and creators of biomimetic androids, dolls and robots
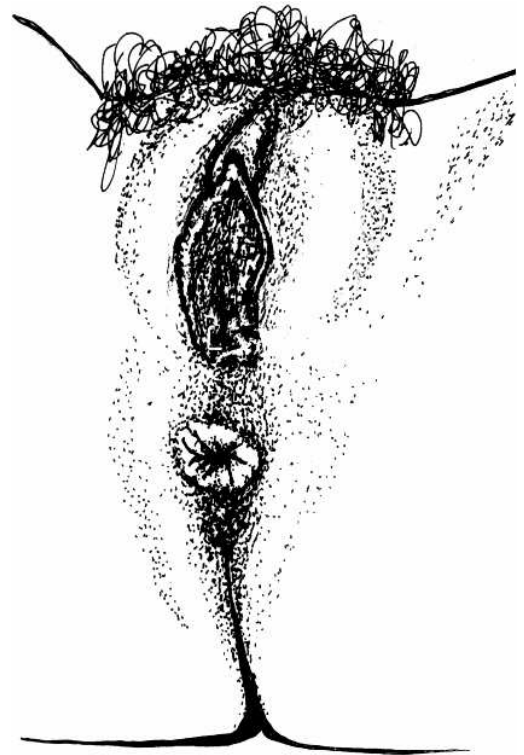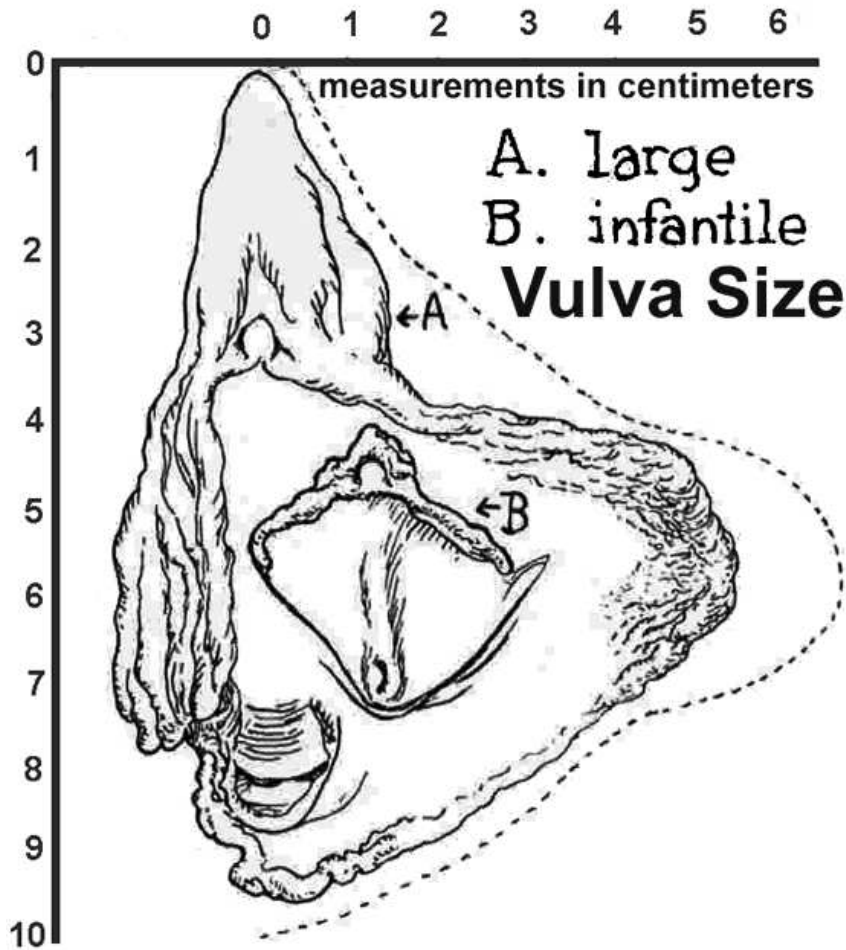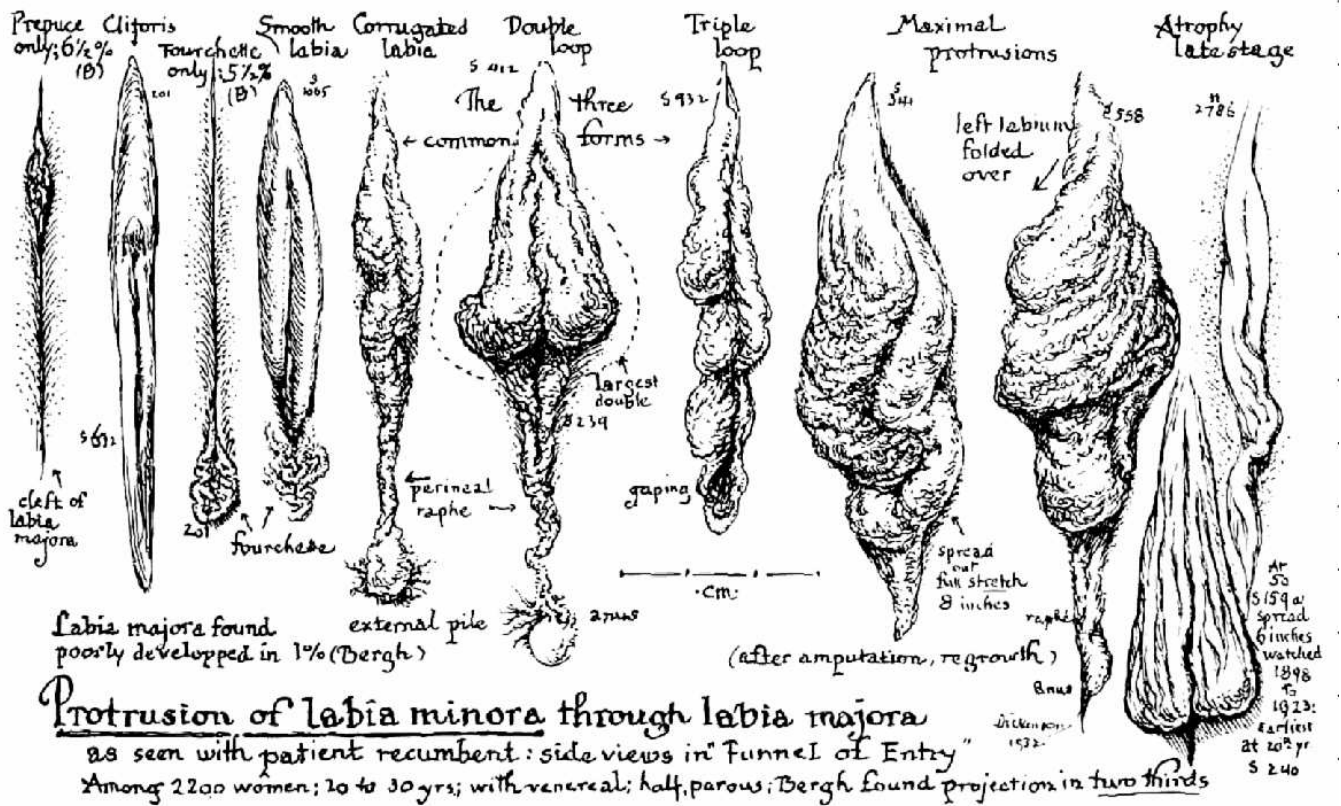
Female External Genitalia

The female external genitalia is known collectively as the vulva. Two lips called the labia majora form the outer part of the vulva and normally enclose the ruest of the parts. Inside the labia majora are two smaller lips, the labia minora. At the front ofthe vulva the labia minoria join the clitoris, a small erectile structure resembling the penis. At the back, the labia minora taper off near the vaginal opening. Between the clitoris and the back of the vulva, a triangular depression called the vestibule contains the urinary meatus (outlet) and the entrance to the vagina.

Much of the vulva is erectile tissue and during stimulation becomes engorged with blood expanding in size. The bulk of the clitoris is hidden under the vulva. The labia majora are composed mainly of fat layers and the area to the front of the of the vulva is a large pad of fat called the mons verneris. The shape of the vulva varies considerably among women.
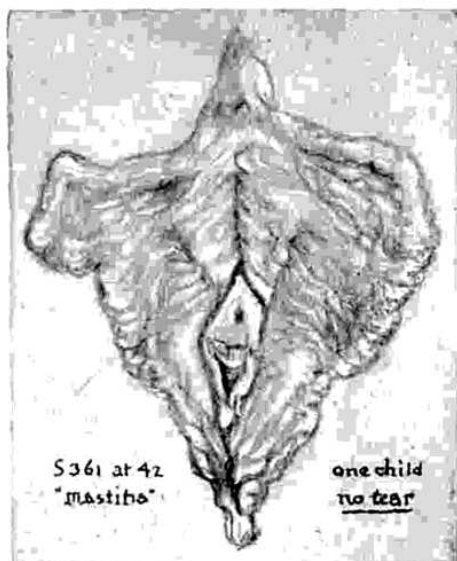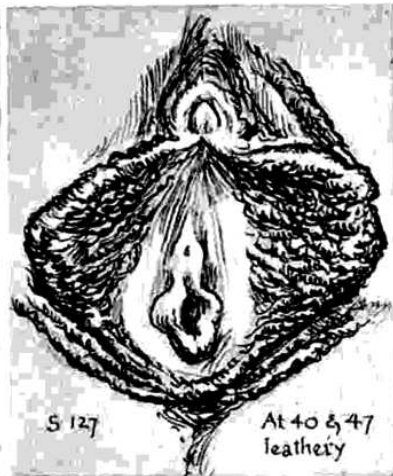
The inner skin of the vulva is hairless and is usually a pinkish color. During sex the color can change to a deep red, purple or blue depending upon the venous structure of the vulva. Women who have been pregnant will often have a more pronounced venous structure of the labia minora, causing it to become dark and bluish during stimulation.

The average length of the vulva (clitoris to vaginal opening) is 54.2mm in the adult, with 66% of all women falling within 11.2mm of this size. The distance from the clitoris to anus is measured at 84mm with 66% of the women falling within 13.9mm of this distance.

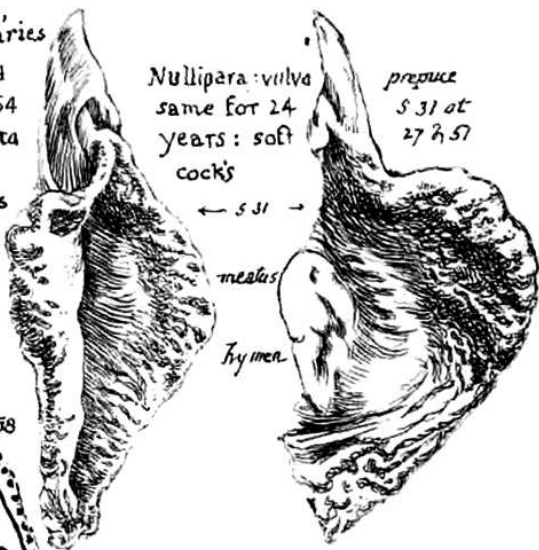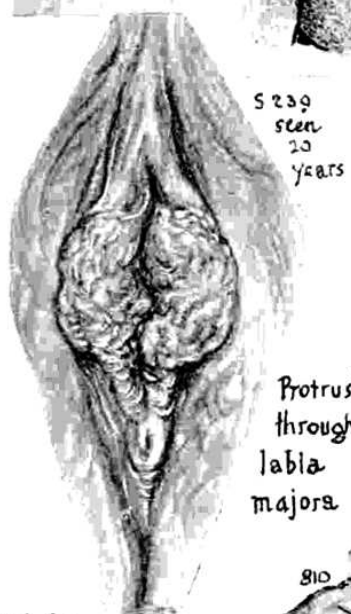Prepuce only; 6½% (B)   Clitoris only; 5½% (B)   Smooth labia   Corrugated labia   Double loop   Triple loop   Maximal protrusions   Atrophy late stage

The three forms
← common.

left labrum folded over

largest double
8239

cleft of labia majora

perineal raphe →

gaping

fourchette

external pile

anus

spread out full stretch 8 inches

raphe

At 50 S159 a spread 6 inches watched 1898 to 1923; earliest at 20th yr S 240

·Cm·

Labia majora found poorly developped in 1% (Bergh)

(after amputation, regrowth)

Anus

Dickinson 1932.

Protrusion of labia minora through labia majora
as seen with patient recumbent: side views in "Funnel of Entry"
Among 2200 women; 20 to 30 yrs; with venereal; half parous; Bergh found projection in two thirds

measurements in centimeters

A. large
B. infantile
Vulva Size

←A

←B

Age 16 8nd Age 17 S707

S 127 At 40 & 47 leathery

S 361 at 42 "mastitis" one child no tear

Limit of mucous membrane, Hart's line, varies

S 163 observed ages 22 to 54 nullipara huge breasts

Nullipara: vulva same for 24 years: soft cock's

prepuce S 31 at 27 & 51

S 239 seen 20 years

hand enters vagina is powerfully sexed

← S 31 →

meatus

hymen

Protrusion through labia majora

558

S 777

Accessory labium: 2" began 817

All are tall vulvas
730 & 558 sisters
140 & 840 sisters

810

777 558

(single) 9 cm 3½"

810

622

(single) 4½

8 inch 558 fullest stretch (combined)

840 730

Hart's line

140

4½" plus 4½' = 9 inches widest span observed by RCD = 23 cm.

Corrugated minora in

140

Youngest, 15-16-17 with very big labia
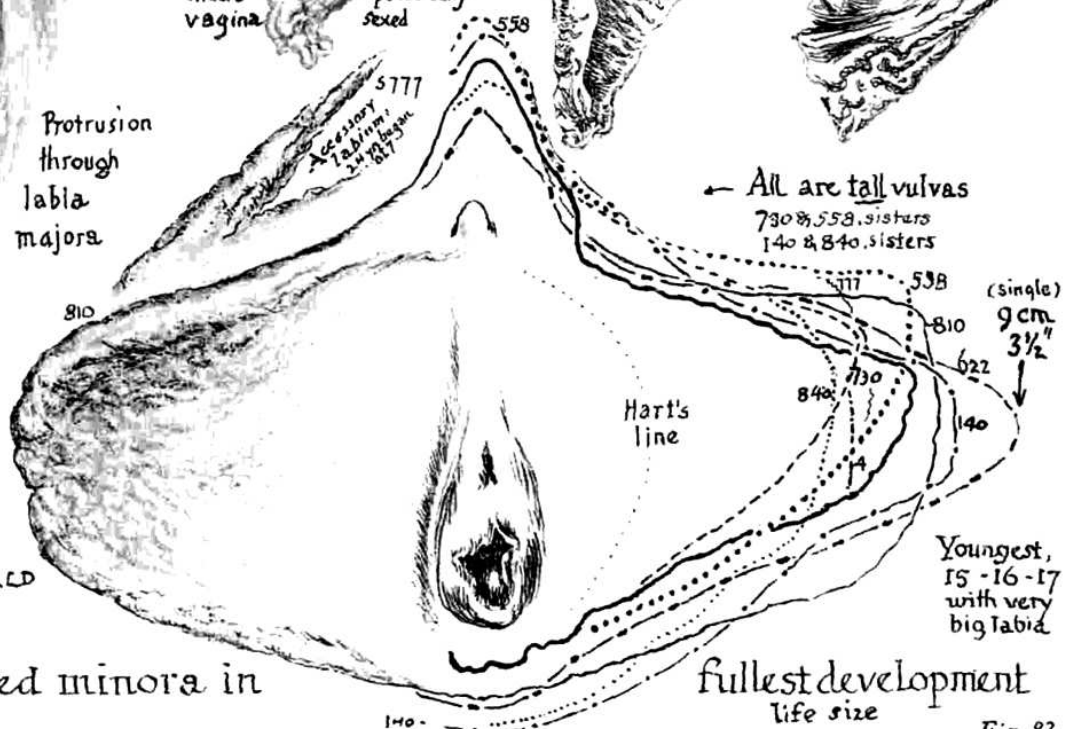
fullest development
life size

Fig. 83

S 738 A
(1900)

S 84

S 159 A

mother & three daughters

S 708   S 403

S 284   4 S 402
labia fully corrugated, soft

2

Acute edema of left labium (recent bout)

Smooth prepuce

Hypertrophy firm cockscomb

Virgin.

tiny clitoris

2

1

1

Atrophy at 52
observed 25 years
no tear in labor

meatus admits finger

2   3

labial late atrophy →
clitoris tiny →

S 712 age 45
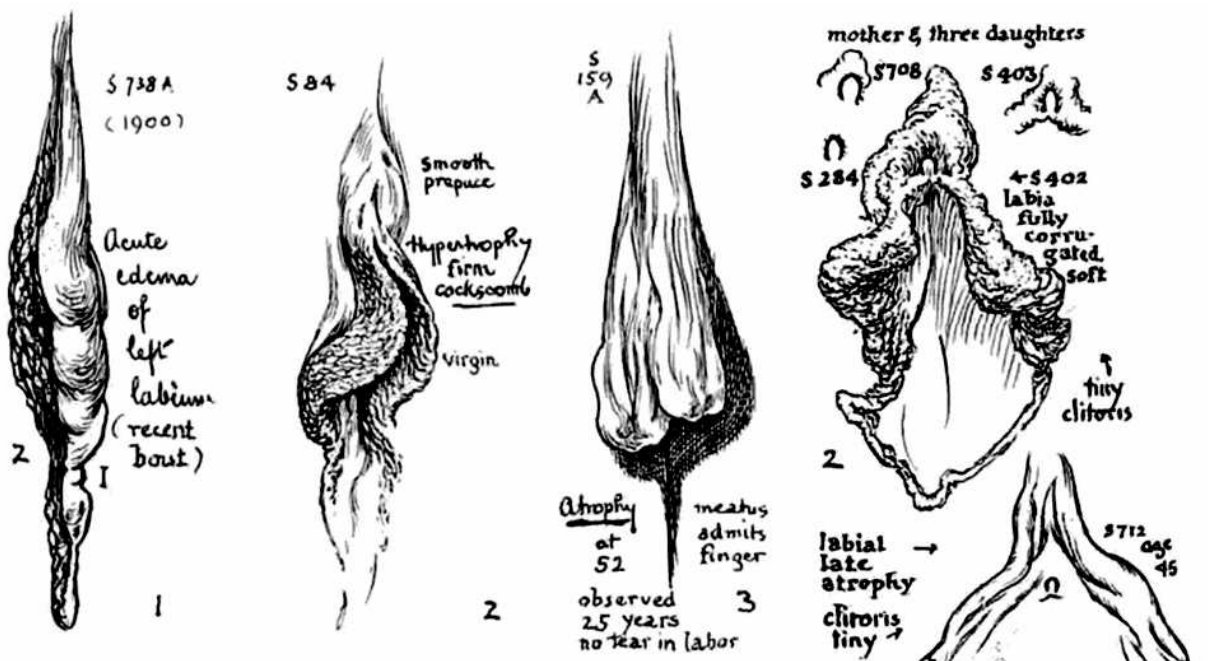
I. Enlargement from acute swelling, oft-repeated, subsiding to wrinkled folds², with later shrinkage to curtain folds, 3. The process is usually more gradual than I.   and I A
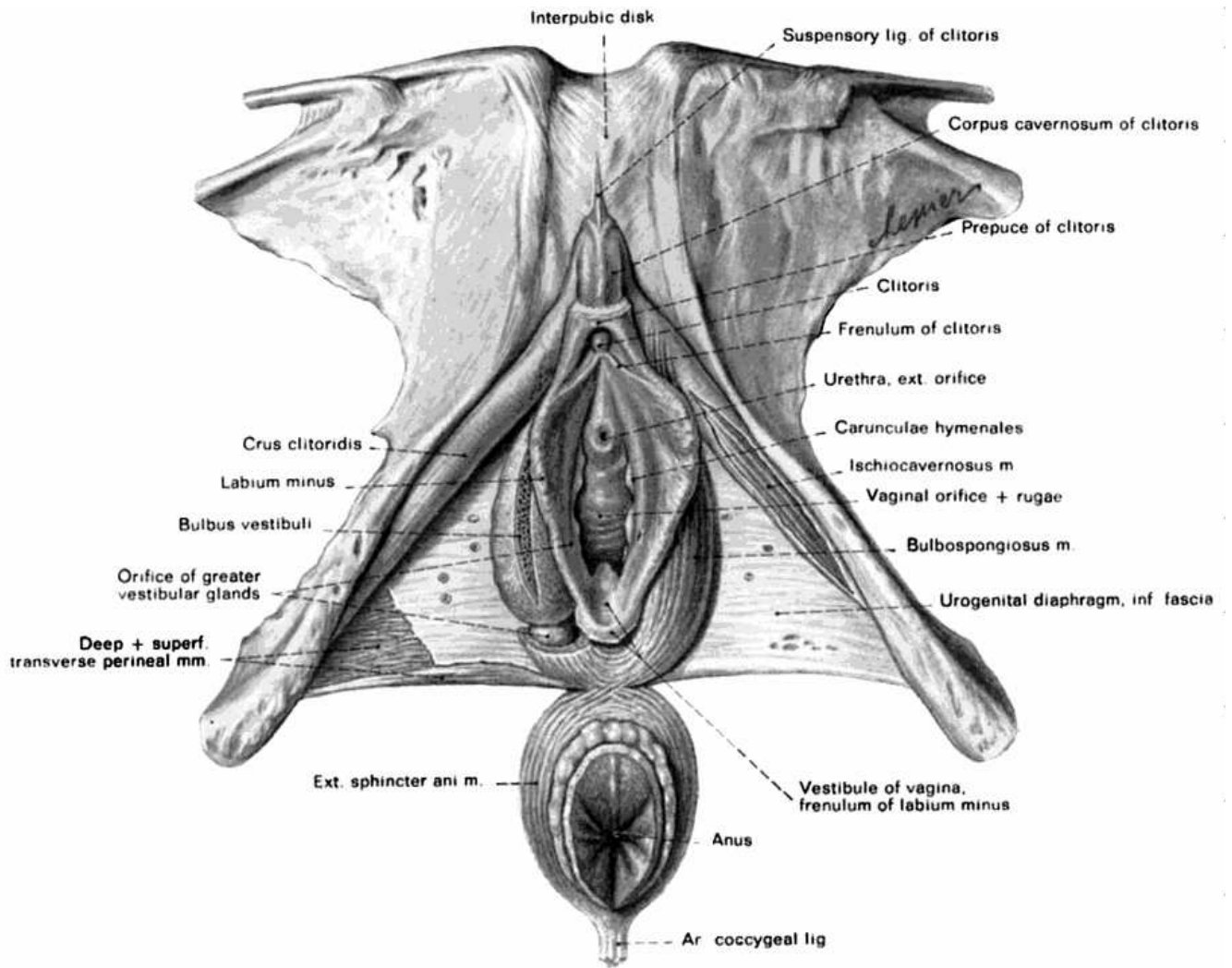
3

1 A

S 89

smooth pinkish white; pits on pressure

brownish wrinkled cockscomb soft stage

symphysis

Acute edema from vigorous, recent, back and forward friction fully stated.

Prepuce

Clitoris

M

Vag.

(measured)
(life-size)

Labium drawn out

Dickinson

Section
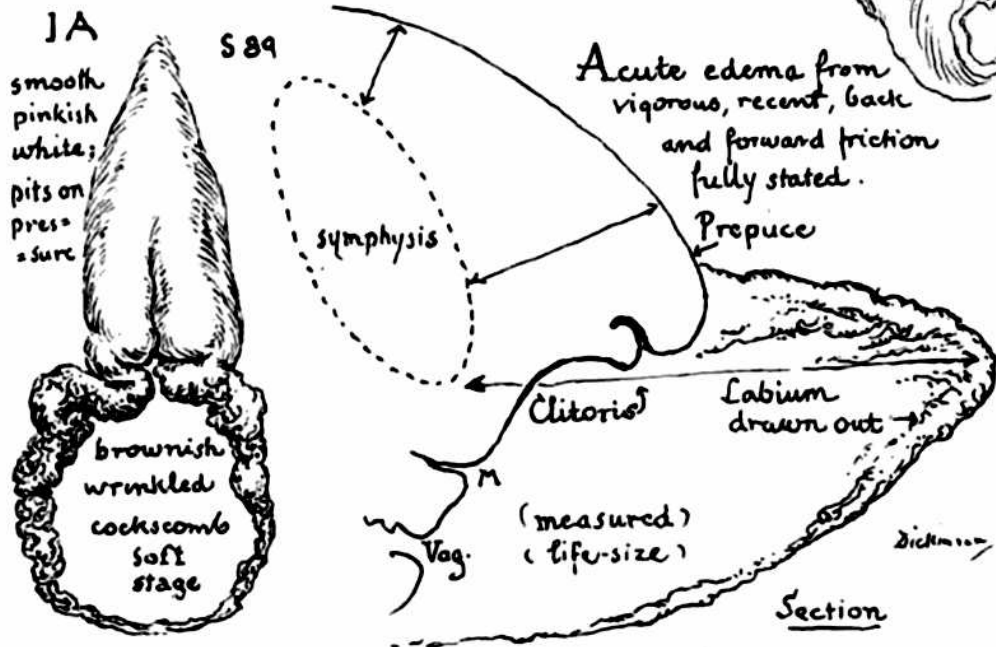
One process in the development of hypertrophies
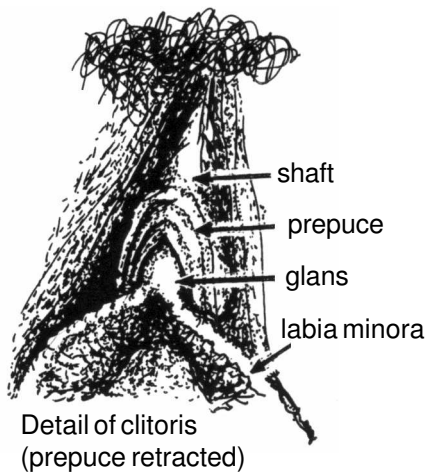1· Contusion-edema : 2 cockscomb, soft or firm : 3· Atrophy

Corrugated labia minora and prepuce: history.

Earliest smooth curtains, 22ᵈ year : at 65 or 70 large minora
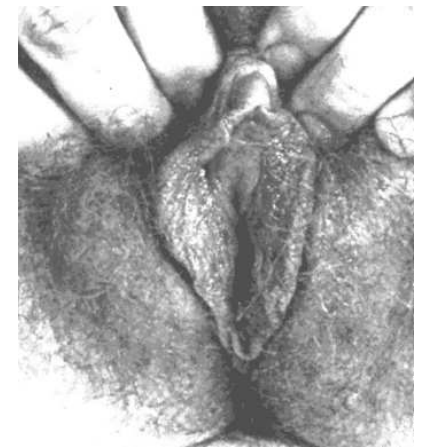may nearly flatten out and clitoris protrude

0   1   2   3   4 in.
0 1 2 3 4 5 6 7 8 9 10 cm.
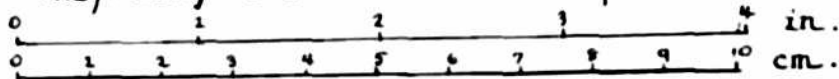
Internal Structure of the External Genitalia
shows attachments to pubic bone and the relationship of the bulbospongiosus muscle and the bulbs of the vestibule (bulbus vestibuli)

Interpubic disk

Suspensory lig. of clitoris

Corpus cavernosum of clitoris

Prepuce of clitoris

Clitoris

Frenulum of clitoris

Urethra, ext. orifice

Carunculae hymenales

Crus clitoridis

Ischiocavernosus m

Labium minus

Vaginal orifice + rugae

Bulbus vestibuli

Bulbospongiosus m.

Orifice of greater vestibular glands

Urogenital diaphragm, inf. fascia

Deep + superf. transverse perineal mm.

Ext. sphincter ani m.

Vestibule of vagina, frenulum of labium minus

Anus

Ar. coccygeal lig

shaft

prepuce

glans

labia minora

Detail of clitoris
(prepuce retracted)

Unstimulated vulva

Stimulated vulva

The glans clitoris (which is the only part of the clitoris normally accessible) has a clitoral index of 30mm to 80mm in the adult (non-erect measure). Clitorial index is determined by multiplying the diameter of the glans by the length of the glans. The length of the clitoral shaft (buried beneath the skin) from the glans to the pubic bone varies between 20mm and 35mm in the adult.

Labia majora are on average about 10mm to 15mm thick. A normal vulva ranges from 63mm to 100mm in length (includes clitoris and vaginal opening) with the average length about 80mm.

Female Internal Genitalia

The length of the vagina is between 4cm and 14cm with the average about 10cm. Due to the tilt of the uterus the vagina is approximately 2cm longer along the posterior wall than along the anterior wall. The vagina is tilted towards the back at
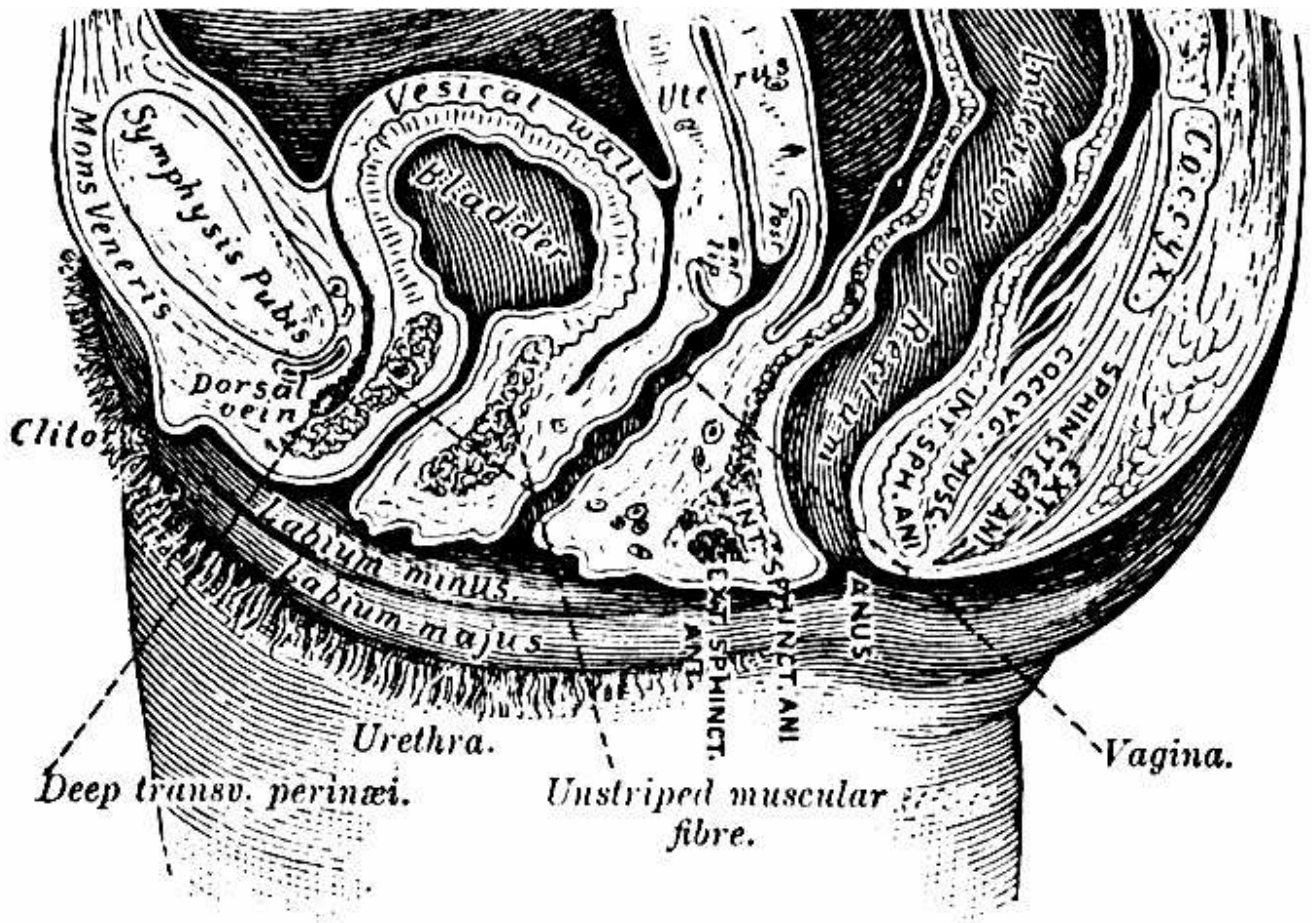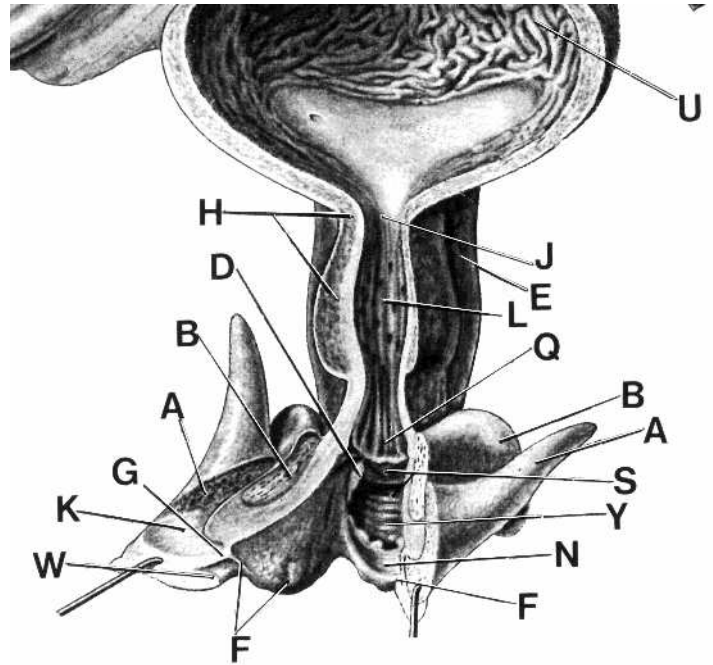
## View of Vagina, Vulva and Urinary Bladder from Rear
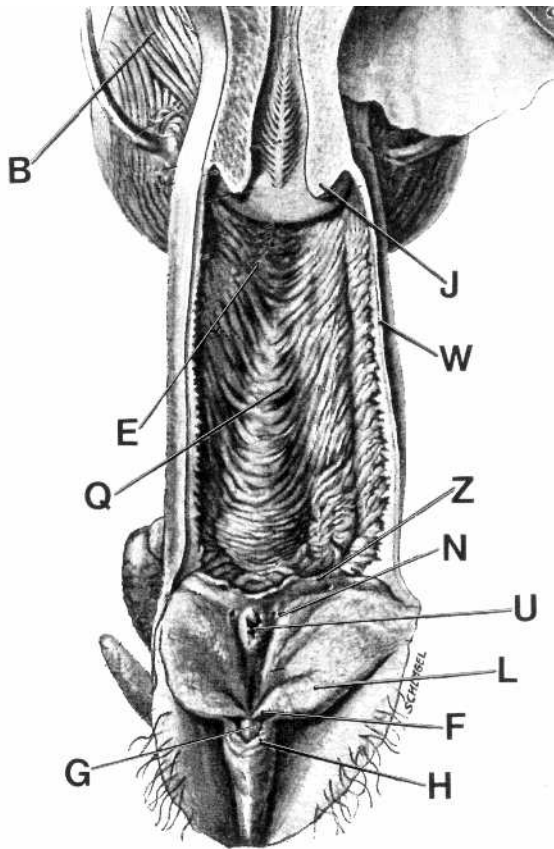
The female sex organs viewed from behind.
(F) frenulum of clitoris, (H) prepuce of clitoris
(G) glans clitoris, (L) labia minora
(U) urethral meatus
(N) duct of gland of Bartholin
(Z) hymen, (W) vaginal wall
(Q) columna rugarum
(E) rugae, (J) cervix
(B) urinary bladder, (K) uterus

View of Vagina, Vulva and Urinary Bladder from Front

The female sex organs viewed from the front.
The urinary bladder, urethra and clitoris are shown split open.
(F) frenulum of clitoris
(N) vestibule of vagina
(W) prepuce of clitoris
(K) corpus clitoris
(G) glans clitoris
(A) crus clitoris
(B) bulb of vestibule
(D) hymen
(S) rugae of vagina
(Y) vaginal opening
(Q) urethral meatus
(L) urethra
(E) vagina
(J) internal urethral opening
(H) urethral sphincter
(U) urinary bladder
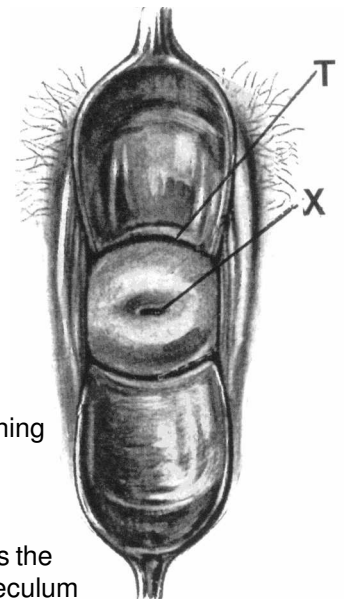
The inset drawing shows the vagina dilated with a speculum so the cervix can be seen.
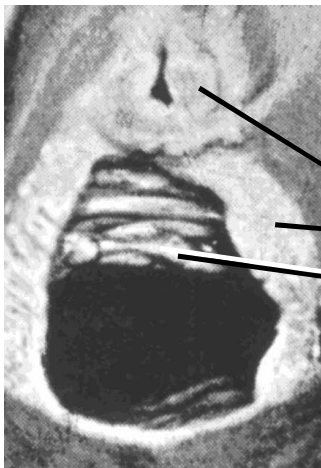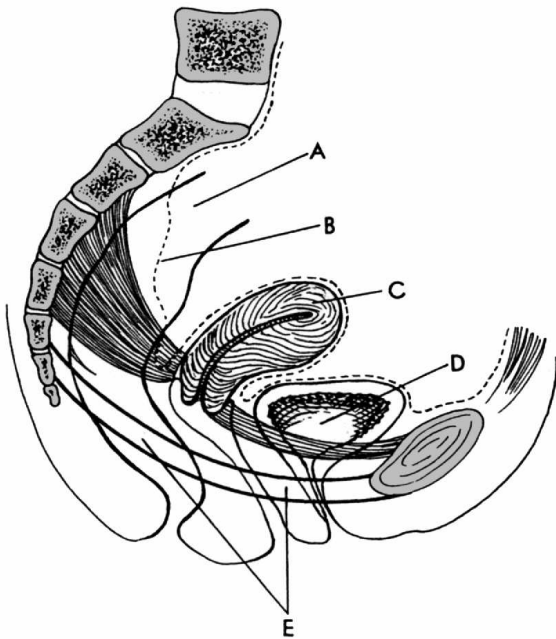(T) vaginal fornix
(X) mouth or os of the cervix

Photo of vestibule
Urinary meatus
hymen and
rugae are clearly
visible

The Pelvic Diaphram
(Levator Ani and Coccygei Muscles)

This is sometimes referred to as the lower pelvic floor. The uterovesical and uterosacral supports are referred to as the upper pelvic floor. The fascial extensions from the cervico-uterine junction to the lateral aspects of the rectum are sometimes referred to as the uterorectal ligaments (A) rectum (B) peritoneum (C) uterus (D) bladder (E) pelvic diaphram
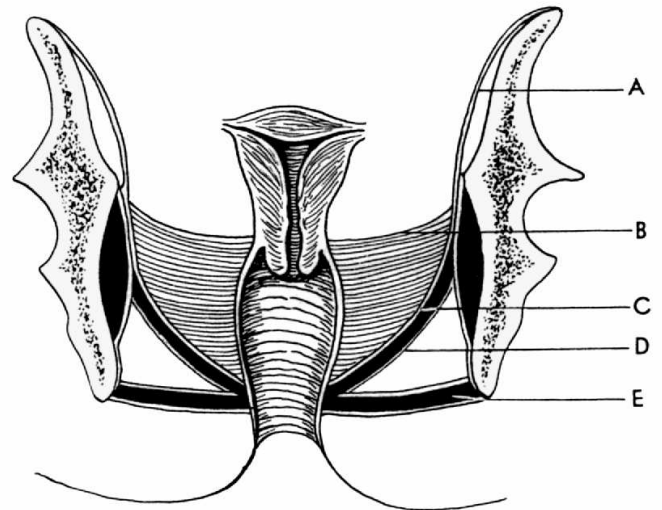
The Pelvic Floor (Female)

Note that the pelvic floor in the female extends from (B) the level of the uterovesical ligaments to the triangular ligament (E). (A) iliac fascia (B) vaginal mesenteroid (C) supra-anal fascia (D) infra-anal (anal) fascia (E) triangular ligament.

From the gynecologic standpoint the upper pelvic floor constitutes the main supports for the uterus, vagina and bladder in the female. The rectum apparently receives no direct support from the upper pelvic floor. Fascial and fasciomuscular extensions of the upper pelvic floor embrace the entire pelvic cirumference and they include the cardinal, uterosacral, pubovesical and vesico-uterine ligaments, as well as the parametrial tissues and the minor but important fascial extensions below the peritoneum. The upper pelvic floor also in-cludes the ureter, the mesenteriods of the vagina and the vascular stalks of the uterus which contain the larger vessels, sympathetic nerve plexuses and lymphatics. Roughly the upper pelvic floor and its main visceral supports consist essentially of the ligamentous and musculofibrous extensions of the superficial pelvic fascia situated below the peritoneum and extending to the lateral pelvic walls.

The Muscle Layer of the Vagina

The muscle layer of the vagina is composed of bundles of muscle fibers arranged in a lattice of decussating spirals. The system is largely independent and confined to the vagina although the muscle fibers are interwoven with the structures of the uterine cervix at the vagino-cervical junction.

Towards the side of the vagina the mesh of the lattice becomes steeper until ultimately the dorsal fibers are vertically orientated. Longitudinal muscle bundles are also present anteriorly in the ventral column of vaginal rugae. A system such as this permits the extreme distension of which the vagina is capable during parturition.

At the lower end of the vagina soft tissue structures press the walls of the vestibule and labia minora together forming a vertical cleft. The intersection of this cleft and the obliquely oriented vaginal lumen constitutes the anatomical closure mechanism of the vaginal orifice. Cranially the vagina and vaginal fornices are attached to the uterine cervix. Muscle bundles from the outer vaginal walls radiate in steep spirals towards the uterine cervix entering it obliquely and extending as far as the internal os. Other fibers lying further inwards curve more acutely over the vaginal vault to the cervix where they interlace with steep bundles originating in the outer layer of the body of the uterus. This system of musculature unfolds during labor when the cervix dilates and is drawn back into the plane of the vagina and lower uterine segment to form the birth canal. Muscle fibers running between the vaginal wall and the urethra form an arch open posteriorly and constitute the nonstriated urethral sphincter muscle.
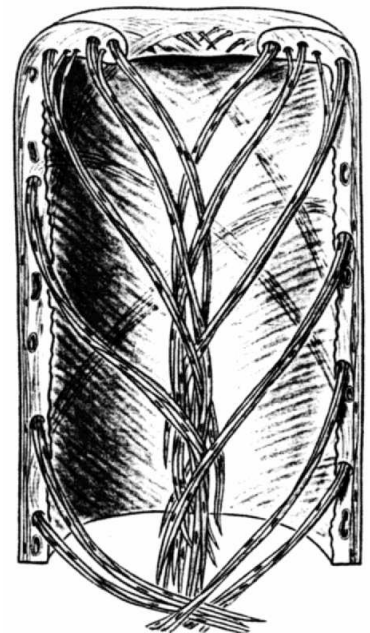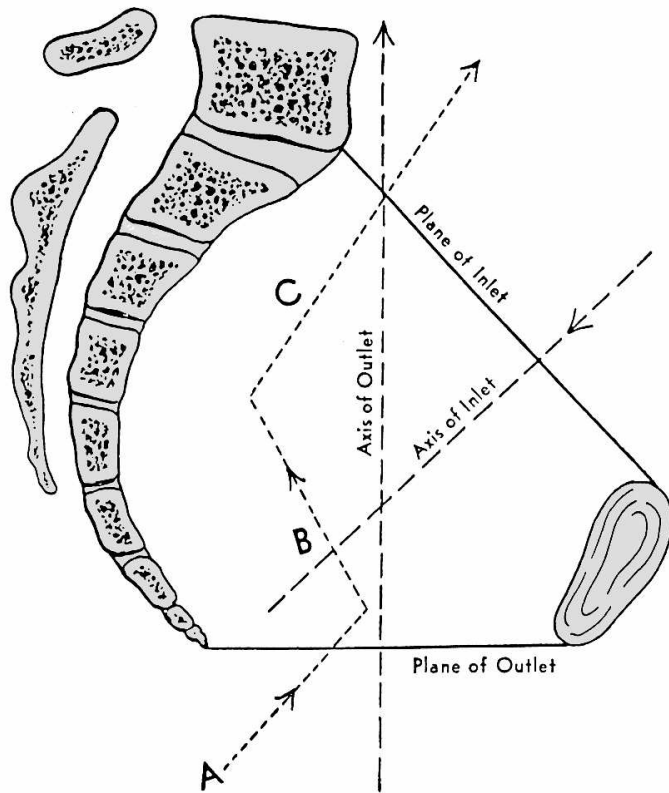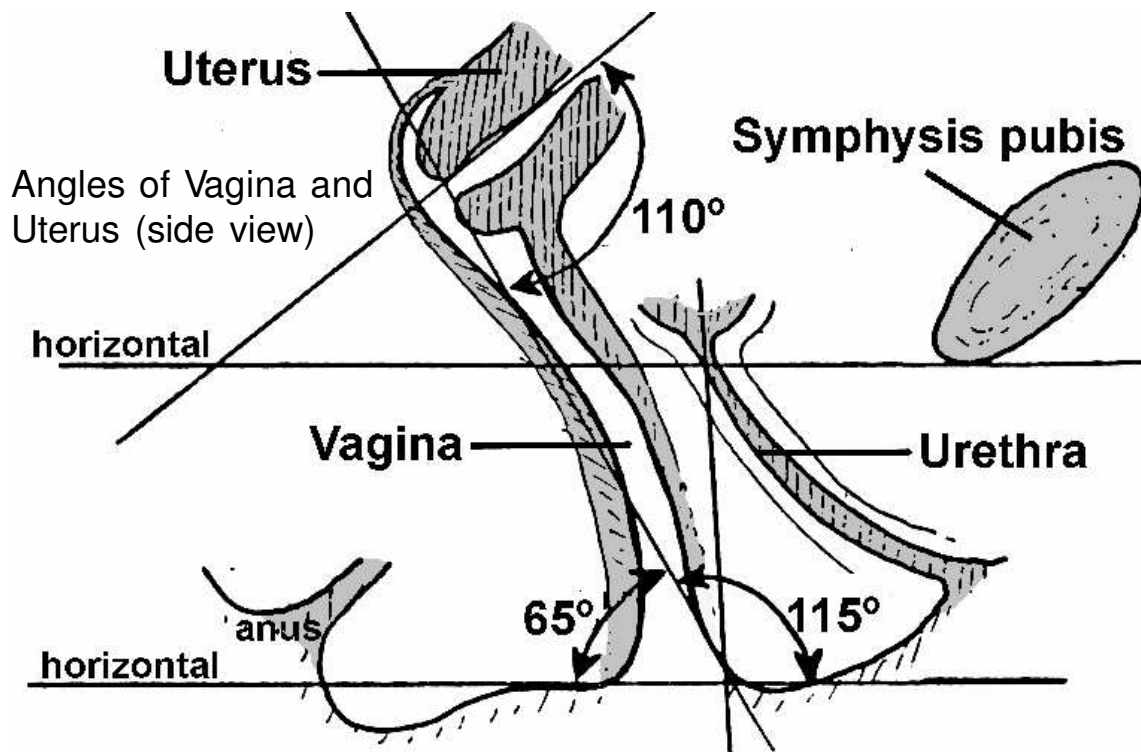
Pelvic Planes (above side view)
(A) the axis of the anal canal
(B) the axis of the rectal ampulla
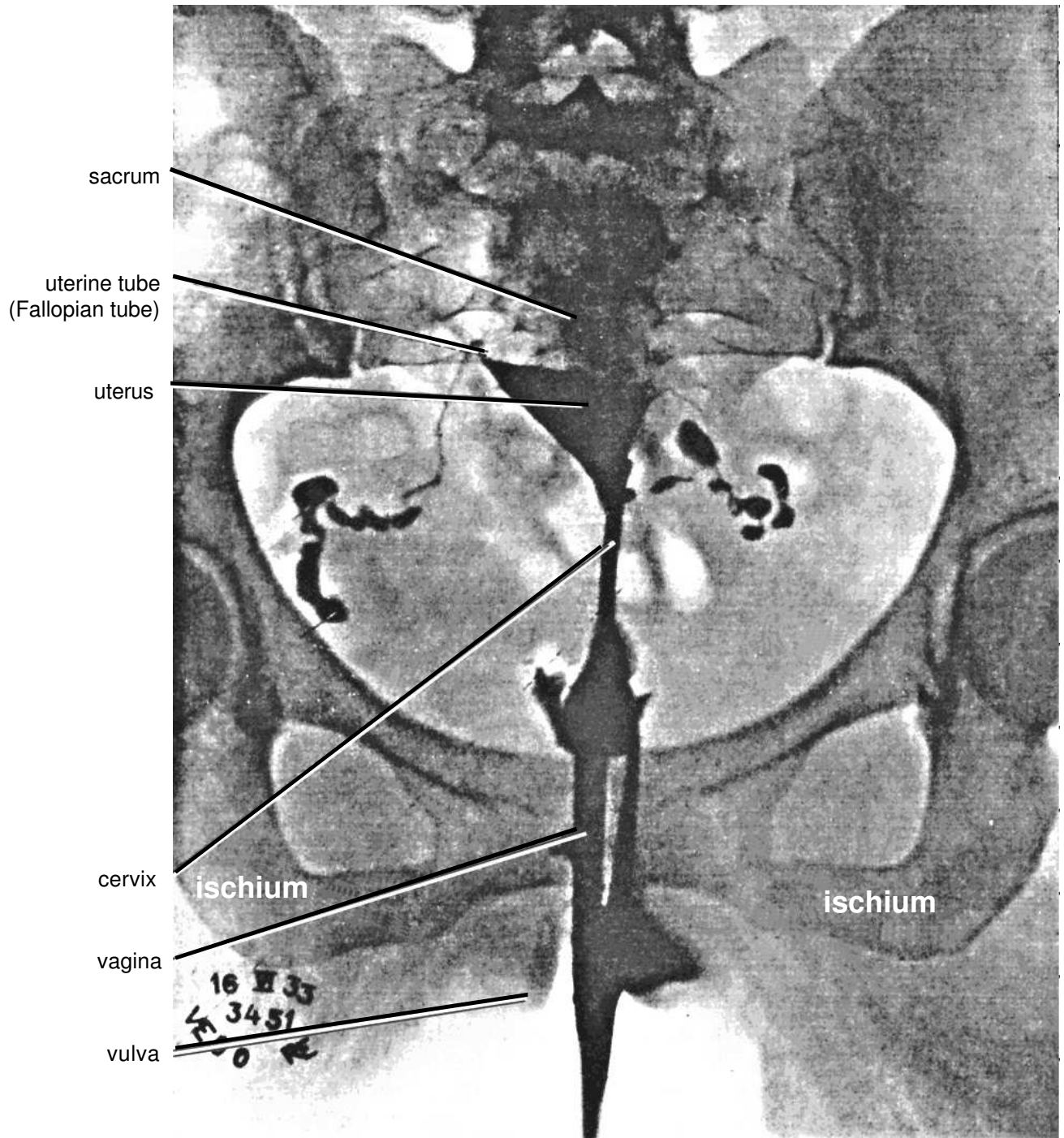(C) the axis of the sigmoid
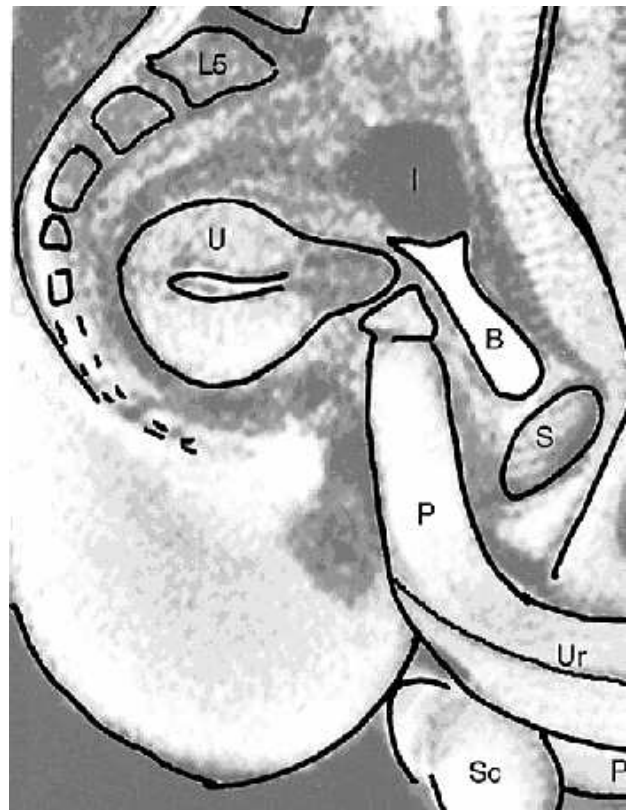
MRI image of female internal genitalia during intercourse. (U) uterus (B) urinary bladder (S) symphysis pubis (P) male penis in vagina
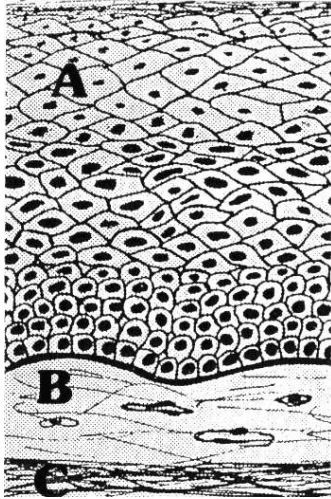

Angles of Vagina and Uterus (side view)

X ray image showing the relationship of the vagina, uterus and pelvic bones
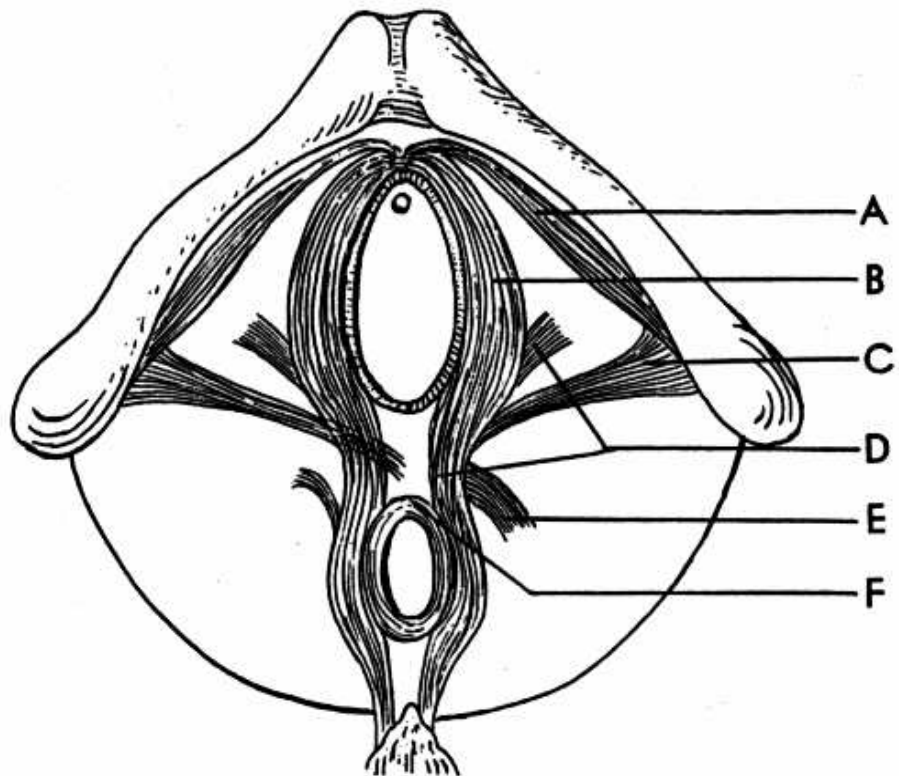An opaque dye fills the vagina, cervix and part of the uterus.

approximately a 65 degree angle to the horizontal and the uterus at an angle of 90 to 110 degrees to the vagina. Vaginal rugae (wrinkles or folds) let the vagina to expand during intercourse or childbirth. The rugae meet toward the midline as a ridge called the columna rugarum. The lining of the vagina is modified skin, although lacking the hardness of normal skin. Beneath the skin is a fibromuscular tissue which is richly supplied with blood vessels called the vaginal plexus. During intercourse this layer of the vagina becomes engorged with blood and turgid. Glycogen (a substance used to store engergy as a starch) is secreted by the vaginal lining; it breaks down into lactic acid which acts as a defence against infection. The vagina is usually collapsed into an 'H' shape with all the walls meeting.

The major muscles of the vagina act within the first third of the vaginal length. Four important muscle groups form the orifice inward are: the ischiocavernosus muscle and superfical muscles, urogenital diaphragm or orgasmic shelf, pubococcygeus muscle (a wide strap-like muscle running under the vagina like a sling) and the intrinsic muscles of the lower end of the vagina. The ischiocavernosus and bulbocavernosus muscles pull the sides of the vagina gently inward and erect the clitoris by compressing the blood vessels in the crus causing blood to be trapped in the tissue. This muscle is near the mouth of the vagina and encircles it. The levator ani muscle pulls upward from the back on the lower third of the vagina. A condition known as vaginismus is caused by the levator ani muscle going into spasms and closing the entrance to the vagina. The pubococygenus is a part of the levator ani muscle and this muscle pulls upward on the vagina though slightly farther back. This muscle contracts involuntarily during orgasm. The end of the vagina is suspended by muscles and fiberous ligaments which radiate outward from where it attaches to the cervix. These muscles and ligaments are attached to the pelvis and help to support both the vagina and the uterus. The vagina has quite a bit of freedom of motion inside the body since it is not firmly bonded to any bones.

Above. The lining of the vagina in cross-section, greatly magnified. The inner-most cells (A) are skin cells without the hair folicles or oil glands that are found in regular skin. (B) the layer of the vagina which becomes engorged with blood (C) the muscular layer of the vagina

THE PERINEAL MUSCLES OF THE FEMALE (SCHEMATIC)
(A) Ischiocavernosus; (B) bulbocavernosus; (C) superficial transverse perineus muscle; (D) superficialis portion of external sphincter ani; (E) fibers of the profundus external sphincter; (F) encircling fibers of the subcutaneous external sphincter ani.
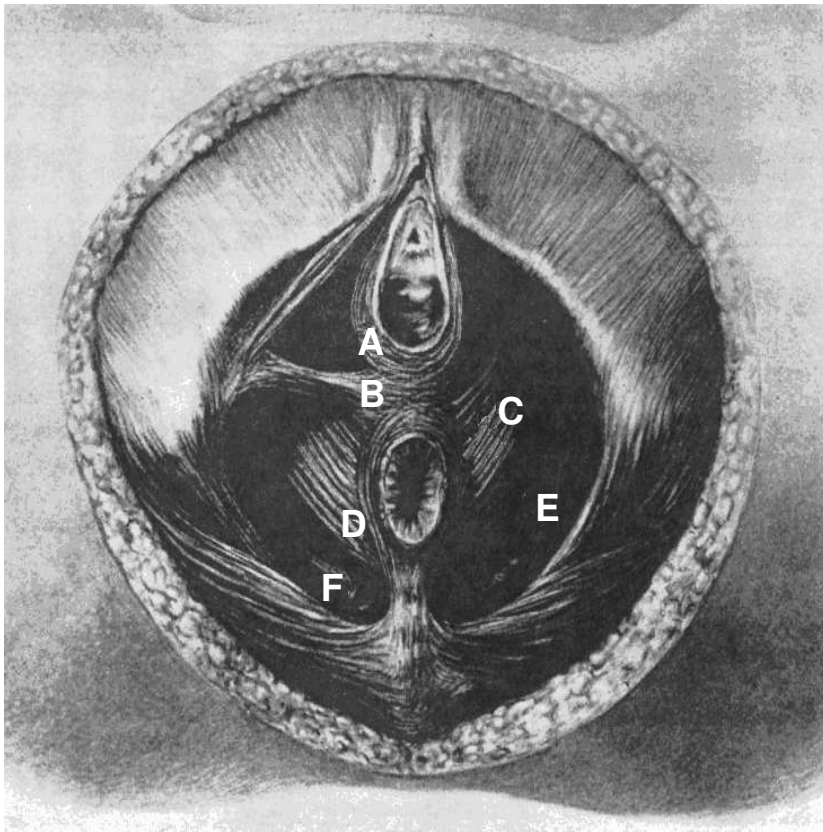
The levator ani muscle in the female from below

Note that the levator legs to the vagina are not shown here but lie deep to the superficial perineal musculature

(A) bulbocavernosus
(B) sup. transverse perineus muscle
(C) pubococcygeus
(D) puborectalis muscle
(E) iliococcygeus
(F) ischiococcygeus

The sling-like arrangement of the pubococcygeal portions of the levator ani muscles is well shown in this dissection

Note their intimate relation to the anal sphincter. The hub of the needle lies in the urethra and the clamps retract the posterior vaginal wall.

(A) ischorectal fossa
(B) urethra
(C) posterior vaginal wall
(D) rectovaginal space (septum)
(E) levator ani legs
(F) anterior rectal wall
(G) external anal sphincter
(H) gluteus
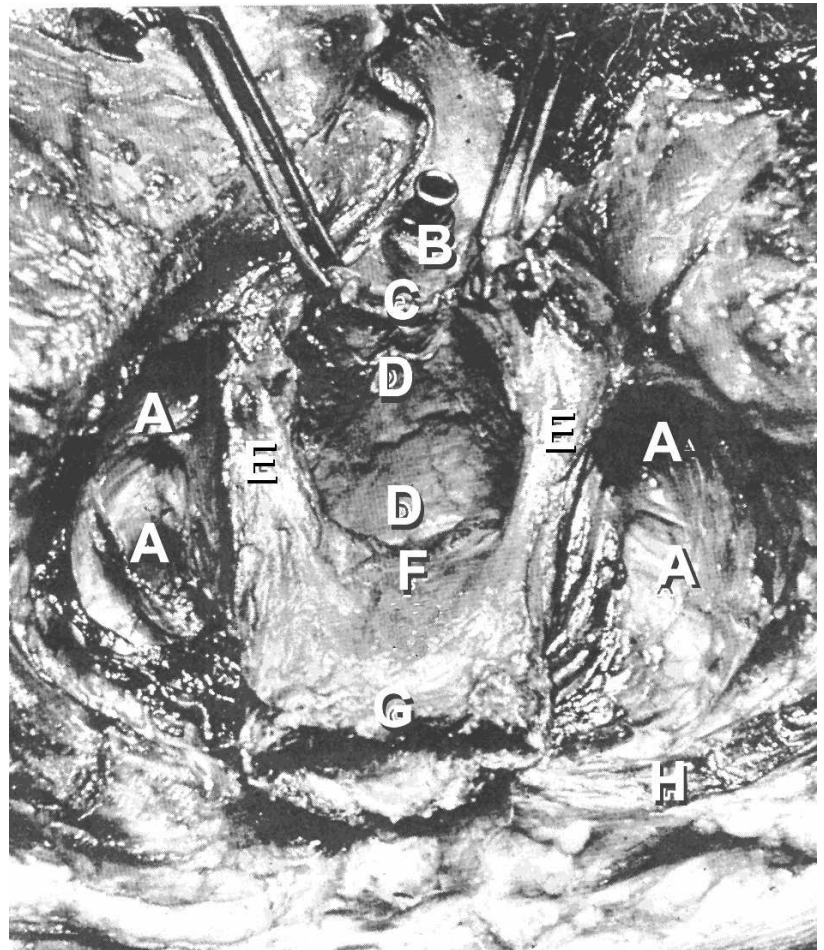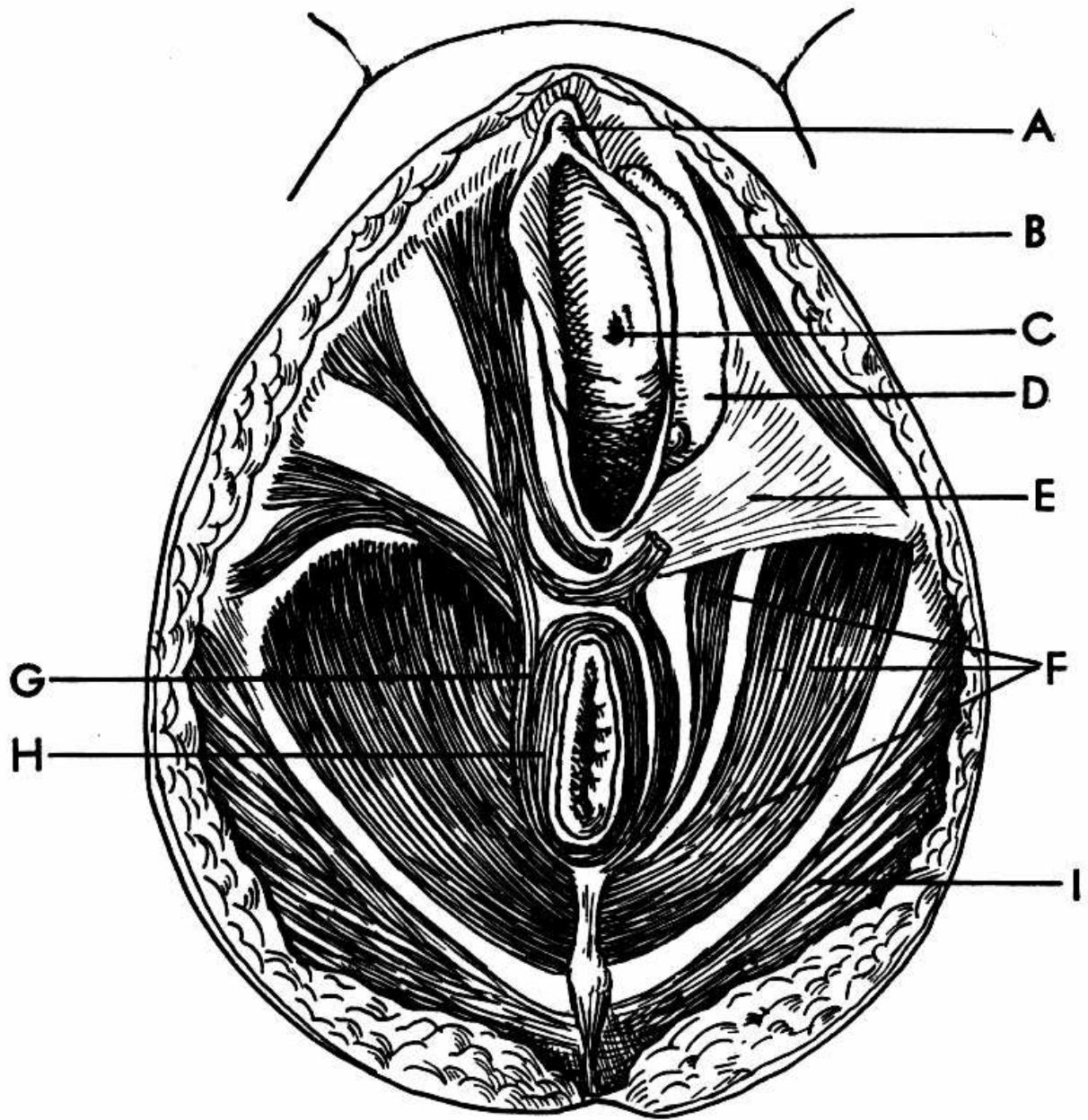
TRIANGULAR LIGAMENT IN THE FEMALE. DRAWN FROM DISSECTION

Note the wing of the triangular ligament on the left side. The superficial perineal muscles have been removed, exposing the bulb. Note also the arrangement of the anterior extensions of the superficialis portion of the external anal sphincter muscle. Its diverging legs reach the pubic arch and many of its fibers fuse with the bulbocavernosus muscle.

(A) Clitoris; (B) ischiocavernosus muscle; (C) urethra; (D) bulb; (E) *triangular ligament;* (F) levator ani; (G) superficial external sphincter muscle; (H) subcutaneous sphincter muscle; (I) gluteus maximus muscle.

The bulbs of the vagina and corpora cavernosa of the clitoris.
Diagram shows relationship of bulbs and cavernosa to the ischium and the vagina
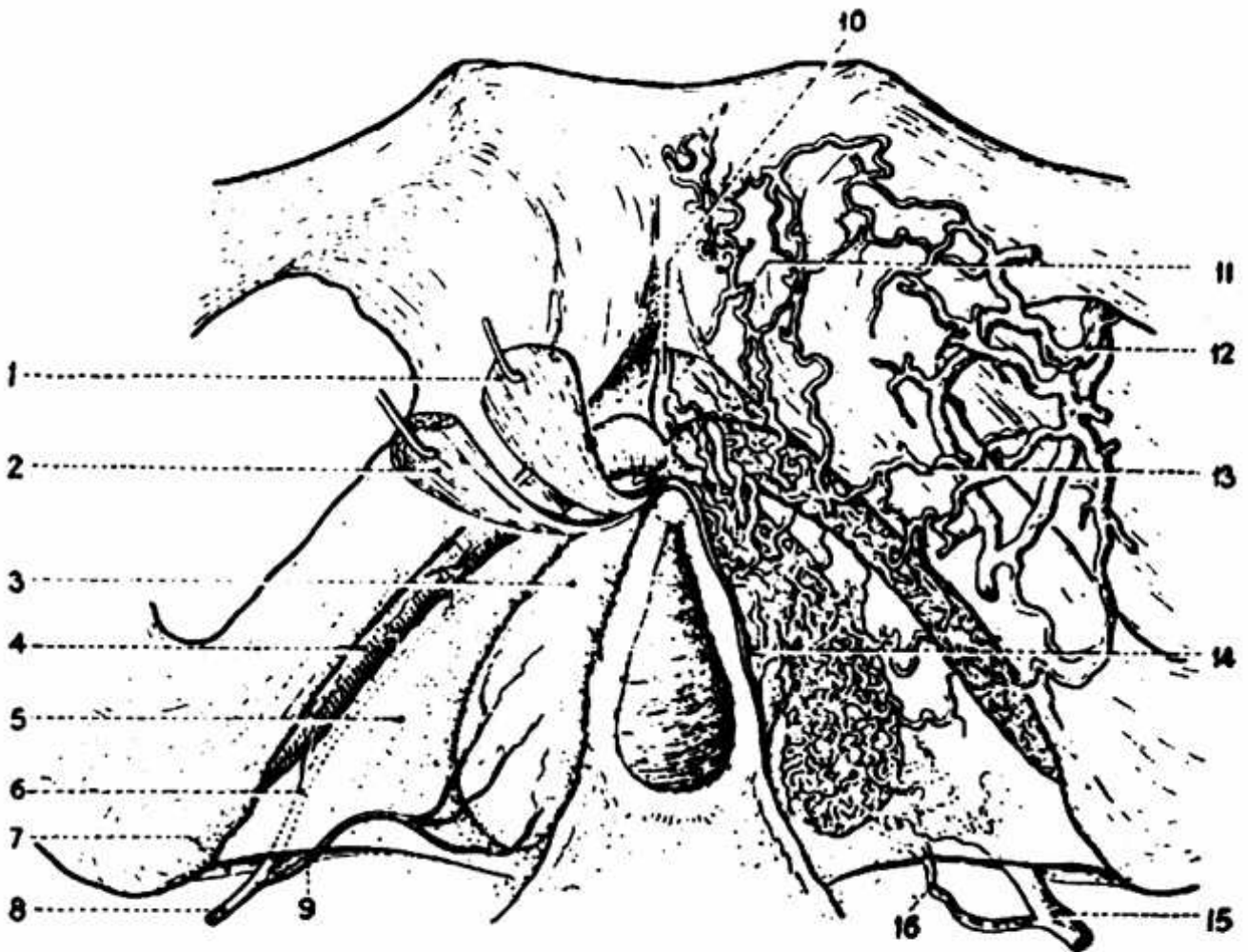

Figure 24. Bulbs of the vagina and the corpora cavernosa of the clitoris, seen from the front. On the patient's right is the artery; on the left are the veins. 1. Bulbocavernosus muscle. 2. Ischiocavernosus muscle. 3. Vaginal bulb in its albugineal sheath. 4. Peripheral portion, corpus cavernosum. 5. Middle perineal fascia. 6. Deep perineal artery. 7. Alcock's canal. 8. Internal pudendal artery. 9. Bulbar artery. 10. Dorsal vein of the clitoris. 11. Connections to the subcutaneous abdominal veins. 12. Obturator vein. 13. Connecting veins. 14. Veins of the labia minora. 15. Internal pudendal vein. 16. Bulbar vein.
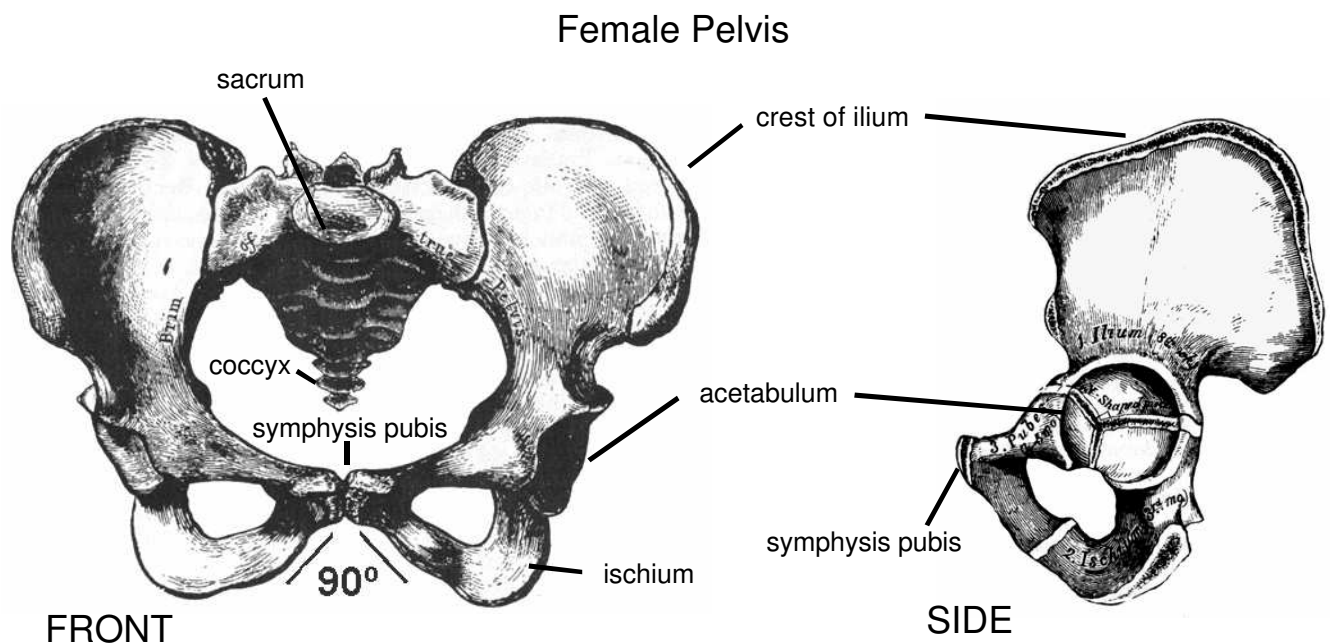
Sexual Response and Orgasm

The first stage of sexual response is the excitment stage. During this stage the vagina expands in length as the uterus moves away from the bladder. Lubrication of the vagina begins within 30 seconds of stimulation as small drops of fluid begin to appear in the vagina by a process similar to sweating; total lubrication during intercourse may amount to several milliliters. The labia majora engorge with blood and spread outward as do the labia minora and the clitoris. The labia minora expand about three times their normal size. The clitoris is pulled down by the action of the pelvic muscles and also expands in size by two or three times, most of this increase is in the diameter of the glans clitors. Continued stimulation leads to continued physical response. The breasts increase in size through engorgement with blood and the nipples become erect.
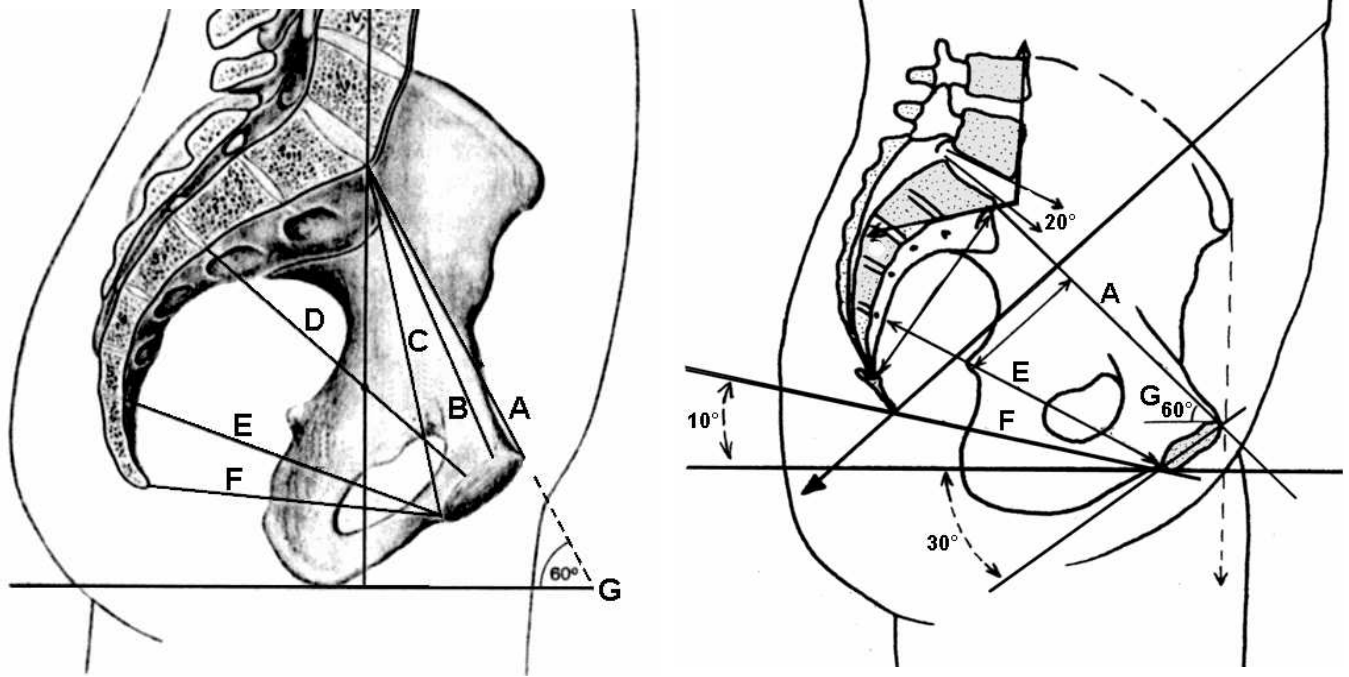
The next stage is the plateau stage which immediately preceeds orgasm or in the case of non-orgasm, the resolution stage. The vagina reaches its maximum length, the vaginal muscles contracting to hold the penis tighter. An orgasmic platform (muscles and vasocongestion of the vaginal lining form a cuff around the erect penis) forms. Signs of approaching orgasm include rapid involuntary pelvic thrusting, hyperventilation, flexing of the fingers and toes, and increased hear and respiration rates (heart rate goes from a normal 72 per minute to as high as 180 per minute, respiration rate increases from 16 to over 40 breaths per minute). The areole of the breasts expands in size.

The muscles near the mouth of the vagina and the lower third of the vagina contract at a rate of 3 or 4 contractions per minute. On top of these slow contractions, the levator ani muscle contracts at the rate of 15 to 20 per minute. Overall vaginal pressure in the outer third of the vagina increases due to the swelling of the smooth lining of the walls. Combining the effects of the various muscles we find that in the lower third of the vagina contractions come in groups of two or three once every twenty seconds or so. These increase in frequency and intensity until orgasm. Maximum pressure occurs approximately 3cm inside the vagina.

A number of involuntary contractions of the orgasmic platform signal orgasm. There are 10 to 15 contractions of the orgasmic platform and the superficial musculature (the ischiocavernosus, bulbocavernosus and transverse perineal muscles), each contraction lasting about 0.8 second and extending over a total period of 20 to 40 seconds. The contractions are of considerable strength and may be seen as a rapid elevation and depression of the clitoris as well as a bowing of the labia minora The pubococcygeus muscle also contracts during orgasm. Pressure exerted by the vagina is equivalent to a pressure of between twenty and thirty millimeters of mercury (a voluntary contraction). In metric this is 2.6kPa to 4.0kPa.

See the following pages for information on muscle contractions during stimulation and orgasm. Study the muscle diagrams to see how the various muscles support and apply pressure to the vagina, anus and clitoris.

Female Pelvis

sacrum

crest of ilium

coccyx

acetabulum

symphysis pubis

symphysis pubis

ischium

90°

FRONT

SIDE

Pelvic Measurments and Inclination (diagrams above)

(A) conjugate diameter at pelvic inlet (B) true conjugate 11.5cm (normal)(C) diagonal conjugate 13cm (normal) (D) pelvic cavity at its widest (E) pelvic cavity at its narrowest (F) pelvic outlet (G) pelvic inclination (60°)
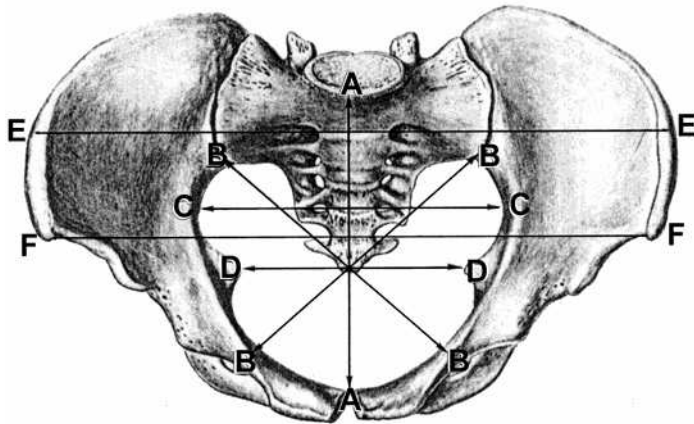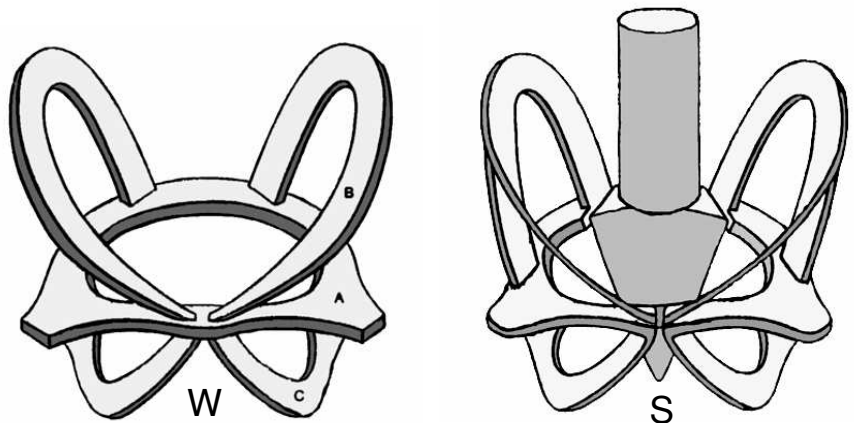

Diameters of the Female Pelvis (diagram left)

(A) conjugate (B) oblique (C) transverse (D) pelvic cavity between ischial spines (E) intercristal distance 29cm (normal) (F) interspinous distance 26cm (normal)
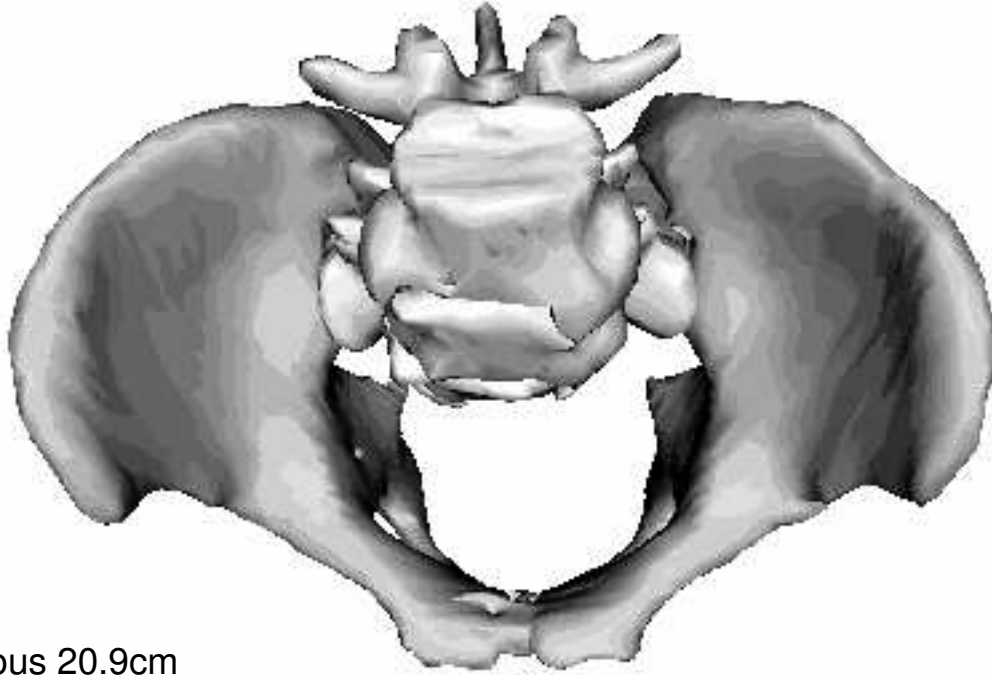
Diagrammatic representations of the Pelvis (diagrams right)

(W) weight bearing framework of the pelvis and (S) the structural framework of the pelvis
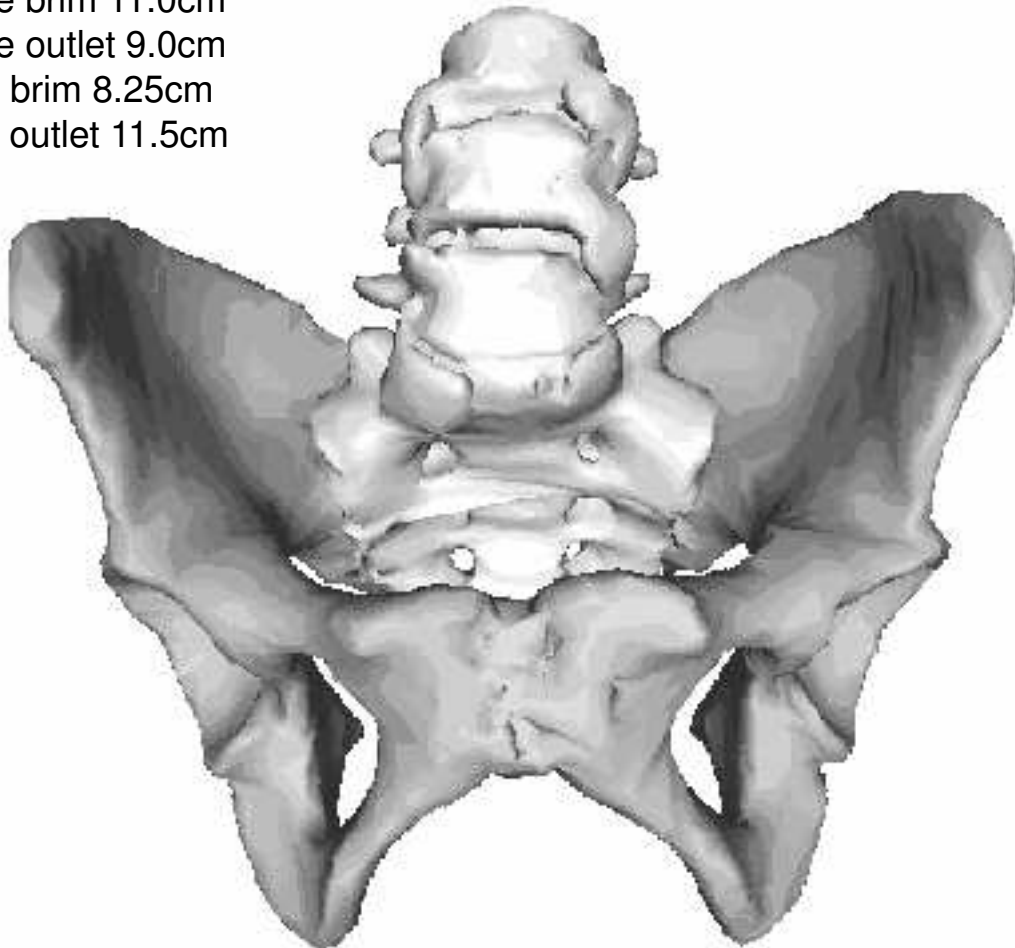

(A) ring of pelvic girdle (B) Cranial span (ilium) (C) Caudal span (ischium and pubis)

Small Round Pelvis
27 year old female

Interspinous 20.9cm
Intercristal 23.5cm
Transverse brim 11.0cm
Transverse outlet 9.0cm
Conjugate brim 8.25cm
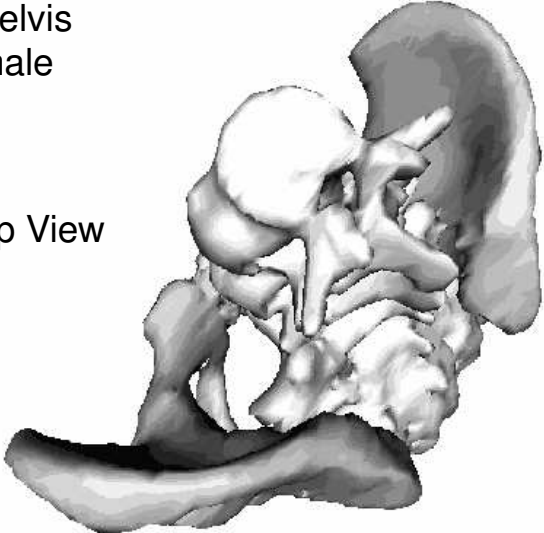Conjugate outlet 11.5cm
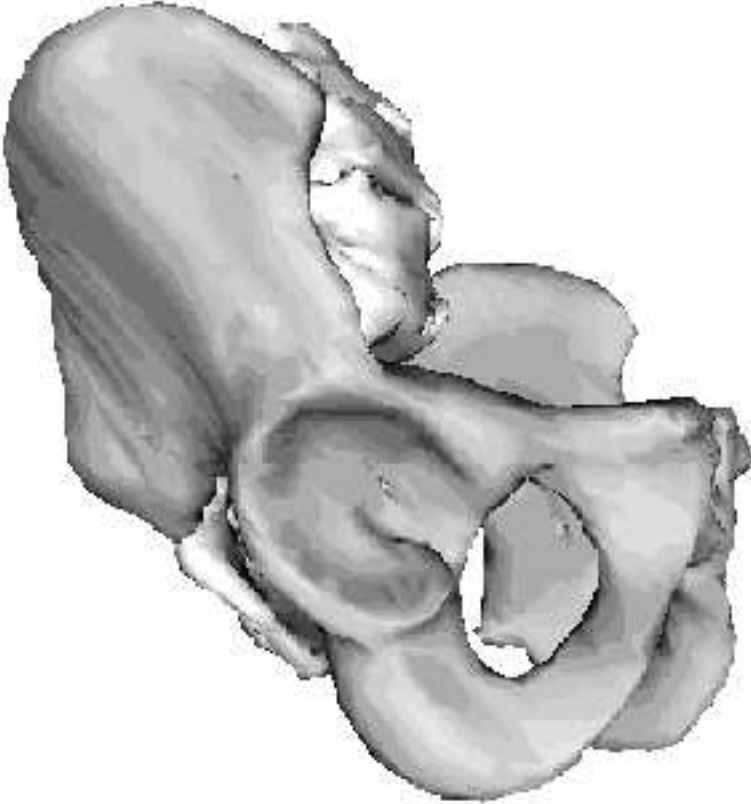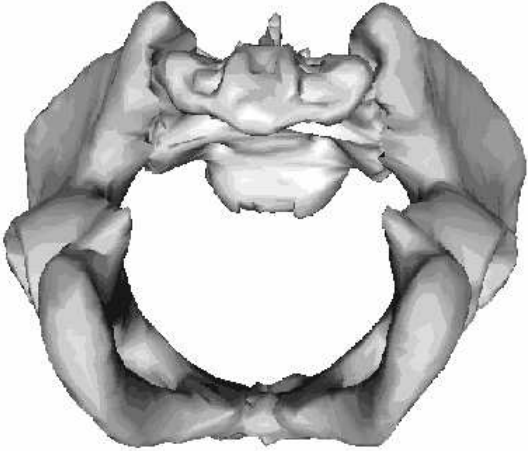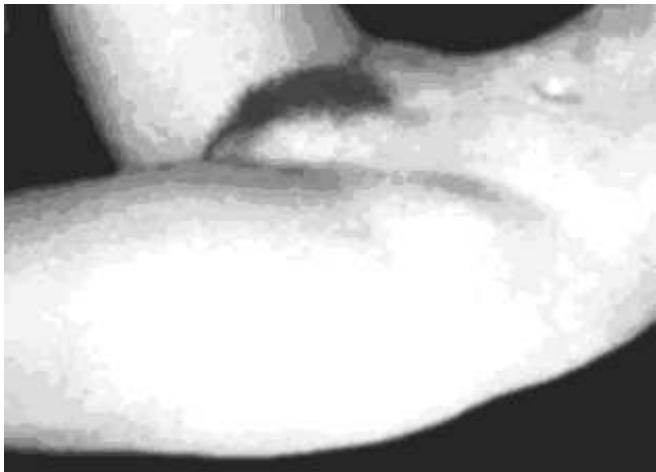
Small Round Pelvis
27 year old female

Top View

Right side views
rotated slightly

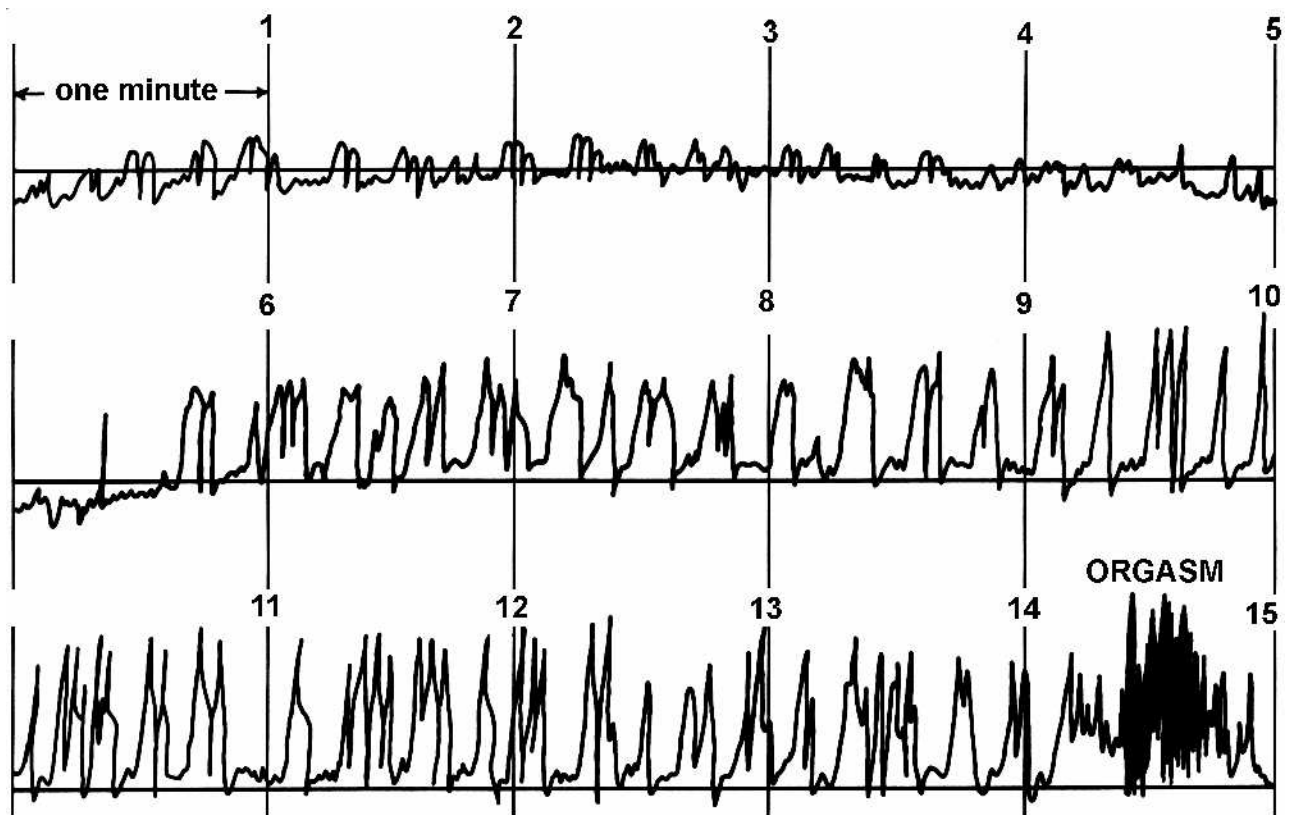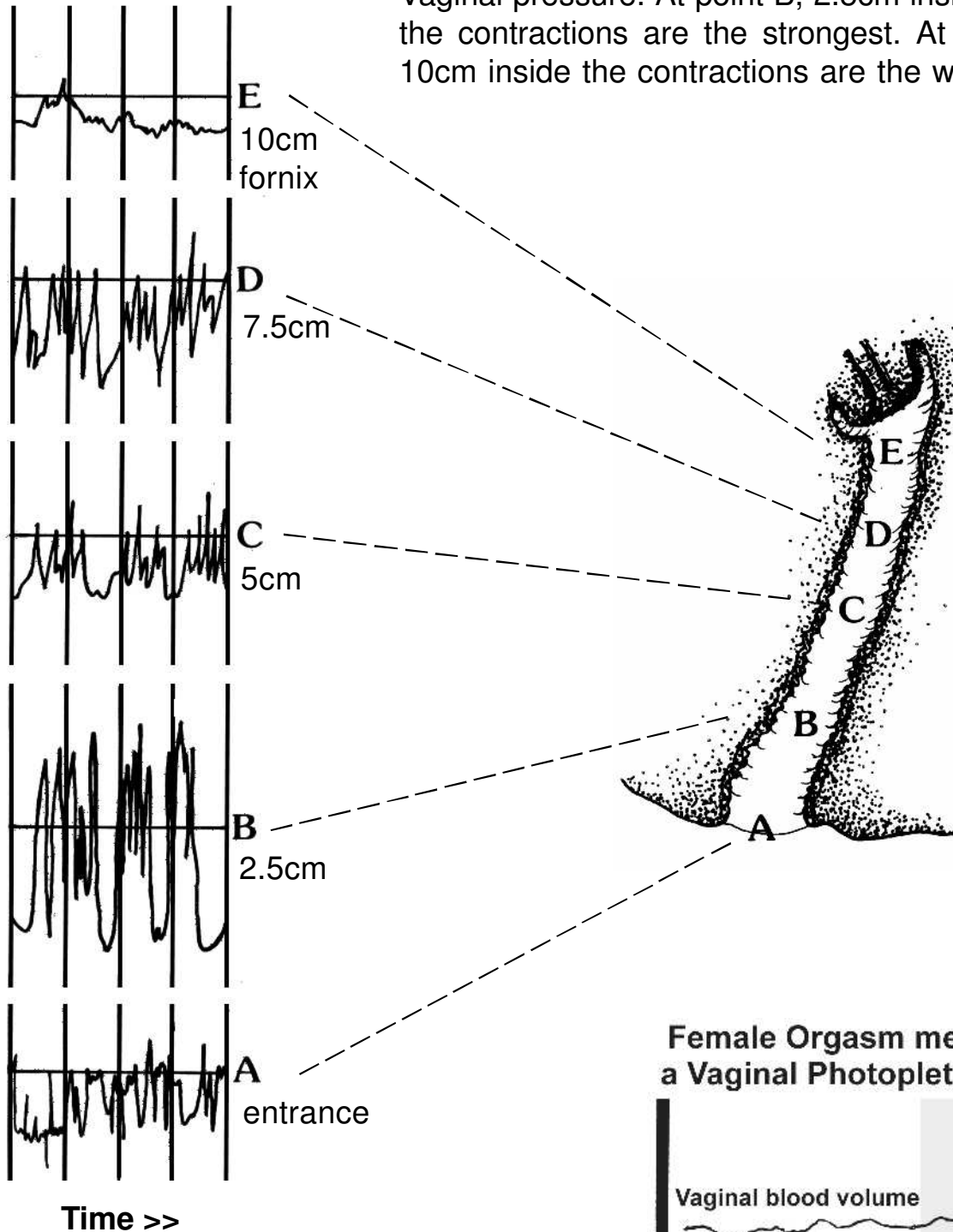View from Below

Pelvic Landmarks

Vaginal pressure during stimulation and orgasm. This figure shows the recording from a pressure sensor located approximately 3cm inside the vaginal opening. Each division is one minute, 15 minutes in total. Maximum pressure about 4.0kPa

Detail of orgasm

The final minute of the sexual response cycle. The closely spaced spiked waves are the orgasmic contractions
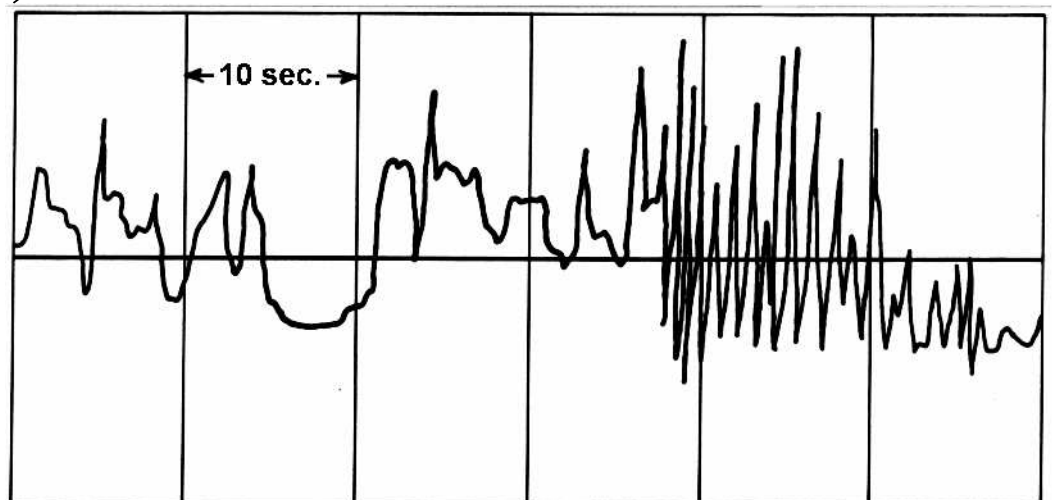
Vaginal pressure. At point B, 2.5cm inside the vagina the contractions are the strongest. At E, the fornix, 10cm inside the contractions are the weakest.

E
10cm
fornix

D
7.5cm

C
5cm

B
2.5cm

A
entrance

Time >>

Blood volume in the vaginal walls during orgasm. Blood volume tightens the vagina. Test subject masturbated to orgasm and indicated beginning and end of her orgasm.

Female Orgasm measured with a Vaginal Photoplethysmograph

Vaginal blood volume

ORGASM

Vaginal pulse pressure

0   1   2
minutes

The rectum and anus
(R) rectum
(A) anus (opening)
(S) sphincter muscle
(M) mucosa lining
(L) muscular lining

The spacing of the rectal valves

Rectosigmoidal junction

10-12cm

8-9cm

5-6cm

Middle valve

15-17cm

Intersphincteric line
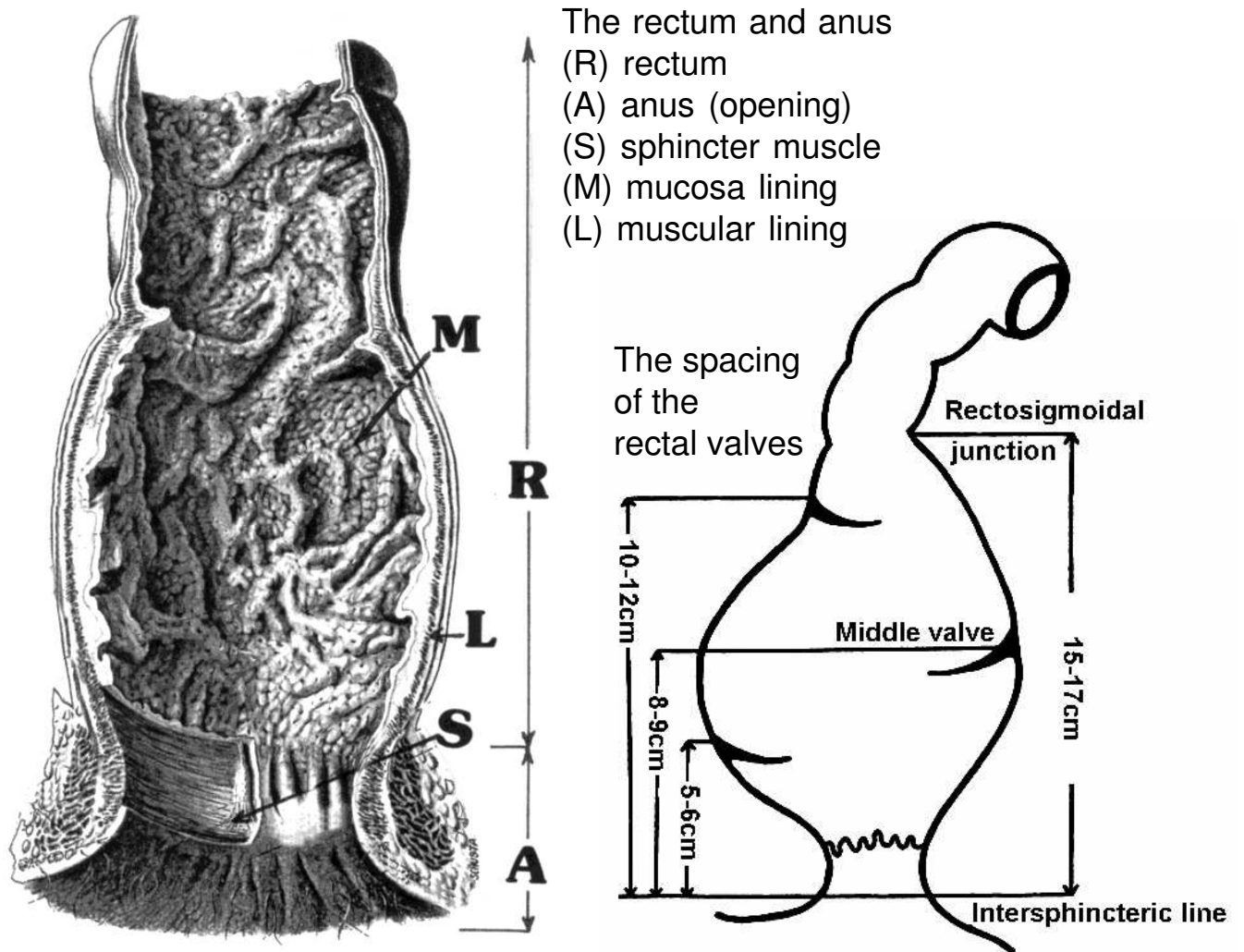
The superficial layer of the anal region (superficial perineal space) is covered by thin skin and contains the cutaneous muscles together with finely lobed adipose tissue. The cutaneous muscles are partly nonstriated and partly striated. The nonstriated muscle bundles are derived from the external muscle coat of the rectum, fibers from which continue as tendinous strands into the subcutaneous fat. They provide an anchorage for the rectum. Because the external longitudinal muscle is absent, the circular muscle predominates and is further reinforced and thickened to form the massive sphincter ani internus muscle.

The superficial (subcutaneous) perineal space also contains the superficial vessels and nerves of the perineal region. When dissecting the anal region special attention must be paid to the cutaneous muscles, which are embedded in thesubcutis. The anal region is a subdivision of the perineal region. Unlike the urogenital region it is divided into two layers: above the superficial (subcutaneous) perineal space there is the supralevator space. Furthermore, the superficial perineal space can be seen to consist of two tiers separated by a boundary lamella. This boundary lamella divides the loose subcuteaneous fat from the coarsely lobed fat ofthe ischiorectal fossa, which lies below the levator ani (infralevator space).

The cutaneous muscles of the perineal region have a common basis in the sphincter cloacae muscle of lower vertebrates. The superficial layer of this sphincter muscle gives rise to the superficial part ofthe sphincter ani externus muscle, the bulbospongiosus muscles (bulbocavernosus muscles) and the ischiocavernosus muscles; the deep layer of the cloacal sphincter give origin to the deep part of the sphincter ani externus muscle and to the muscles of the urogental triogone.

The superficial subcutaneous layer of the anal region (superficial perineal space) contains finelylobulated fat, in which lie radiating strands from the sphincter ani externus muscle, connected with the anal canal.

The sphincter ani externus muscle is situated at the lower end of the rectum, encircling the anal canal. It forms a ring 2-3 cm in height and is subdivided into superficial and deep portions. The superficial portion crosses in front of and behind the anus, while the more deeply situated bundles run to the coccyx and anococcygeal ligament posteriorly. Anteriorly, some bundles radiate into the bulbospongiosus muscle (bulbocavernosus muscle), so that viewed as a whole it forms a figure-of-eight pattern. The sphincter ani externus muscle is supplied by the pudendal nerve, which runs in company with and anterior to the inferior rectal vessels.

The Superficial layer. The skin is thin, smooth and soft. It may be pigmented and it contains numerous glands in the vicinity of the anus. 1-1.5 cm from the anal orifice there is a circle, up to 2 cm in breadth, containing numerous convoluted glands known as the circumanal glands.
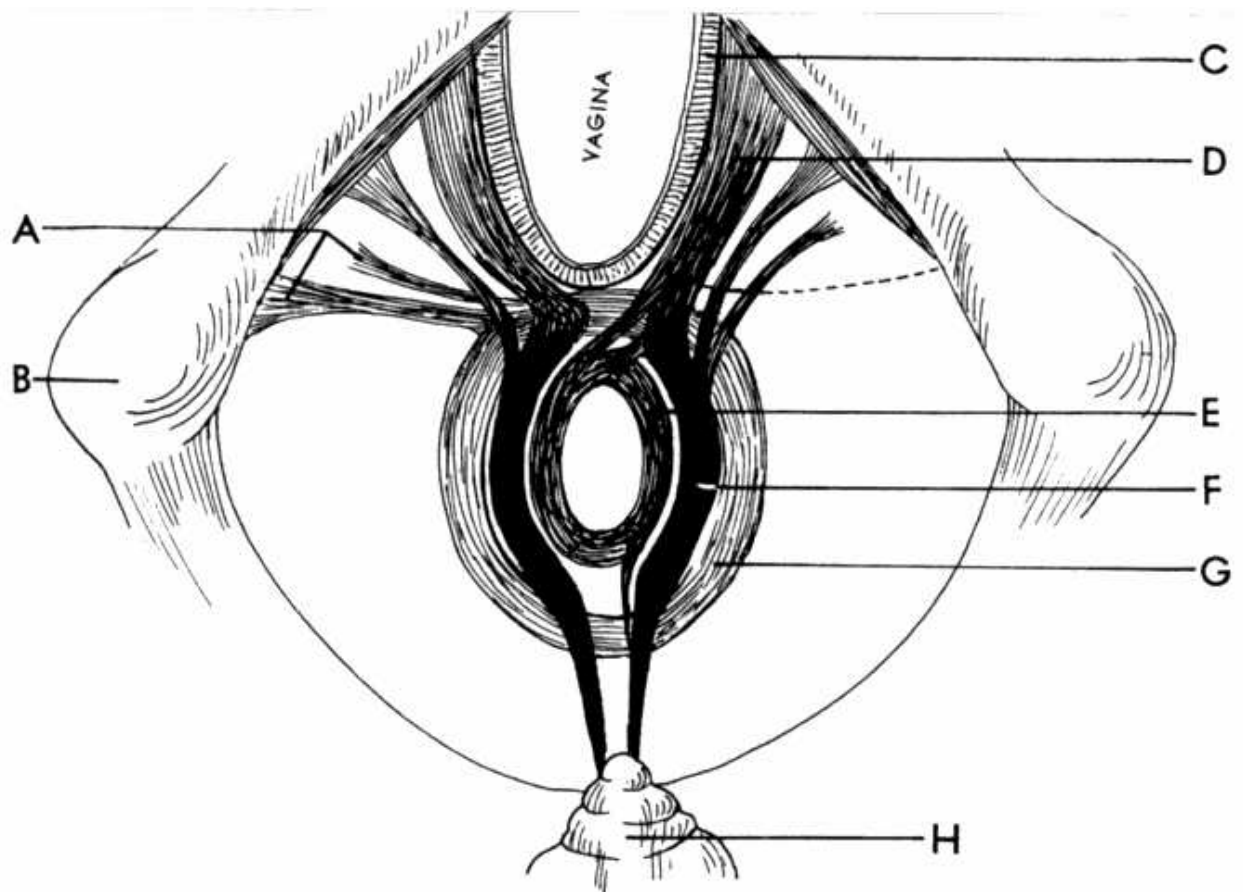
EXTERNAL ANAL SPHINCTER IN THE FEMALE (SCHEMATIC)

Note that the *subcutaneous* portion of the external sphincter is usually annular but may partially decussate anteriorly or, less commonly, posteriorly. The *superficialis* arises, as in the male, from the sides of the coccyx, and surrounds the midportion of the anal canal in a spindle-shaped manner. Many of its fibers become continuous with the bulbocavernosus of the same side and additional small bundles of uncrossed fibers extending to the pubic rami are commonly found. Some of its fibers insert into the perineal body. The *profundus* portion, in close relation to the puborectalis posteriorly, surrounds the anal canal in an annular fashion. Its fibers may insert into the central perineal tendon. In many cases, however, the bulk of its fibers cross and, becoming continuous with the superficial transverse perineal muscle, insert into the pubic ramus of the opposite side. The free borders of the levator ani muscles forming the genital hiatus are in close relation to these fibers of the profundus external sphincter.

(A) Crossed fibers of profundus external sphincter ani; (B) ischial tuberosity; (C) vaginal wall; (D) bulbocavernosus; (E) subcutaneous external sphincter ani; (F) superficialis external sphincter ani; (G) profundus external sphincter ani; (H) coccyx.