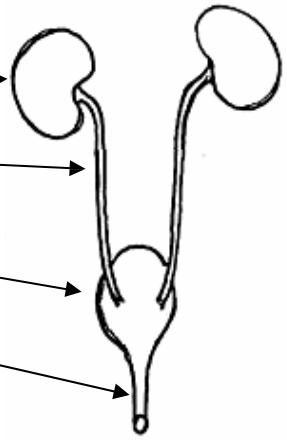
# Veterinary Bioscience: Metabolism

## LECTURE 17: ANATOMY OF THE URINARY SYSTEM

### General

The urinary tract consists of:

- kidneys - paired 1° organs of system, continuously **producing urine**
- ureters - paired muscular tubes, **conducting urine to bladder**
- urinary bladder - a muscular reservoir, for **storing urine**
- urethra - single muscular tube, **conveying urine to exterior**



**Functions of the urinary system:**

- form urine by the filtration of blood and reabsorption and secretion of urinary constituents
- excretion of waste products
- stabilise body fluid composition (osmolality, electrolyte balance) and volume
- regulation of blood pressure
- regulation of acid-base balance
- endocrine (renin – BP, Na, K regulation, erythropoietin – RBCs, activation of Vit D to calcitriol)

**Location and structural relationships:**

Kidneys:

- Located ventral to the sublumbar muscles, usually on either side of the vertebral column. They may lie, to a variable extent, medial to the caudal ribs.
- Are retroperitoneal (external to the parietal peritoneum and thus not strictly within the abdominal cavity)
- Depending on degree of attachment – the right kidney is usually cranial to left and usually more tightly anchored to abdominal roof than the left, which may therefore be more mobile.
- They are generally covered by fat (perirenal), the amount depending on diet and species. The fat is protective and acts to stabilize the organs.

Ureters:

- One ureter passes caudally from each kidney along the dorsal abdominal wall before descending ventrally towards the bladder.
- The ureters pass ventrally on either side of the descending colon and in females pass through the broad ligaments on either side of the reproductive tract to enter the dorsal aspect of the caudal part of the bladder close to the bladder neck.

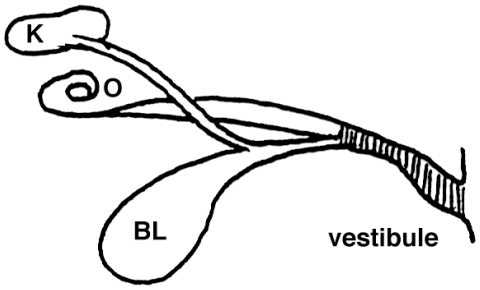
Bladder:

- When empty lies mostly within the pelvic cavity in larger animals and projects into the abdomen in carnivores. As it fills the body of the bladder increasingly projects cranially into the abdominal cavity.
- Lies ventral to the uterus and vagina in female animals and to the terminations of the deferent ducts in the male. Dorsal to these reproductive structures is the descending colon in the abdominal cavity and rectum within the pelvic cavity.

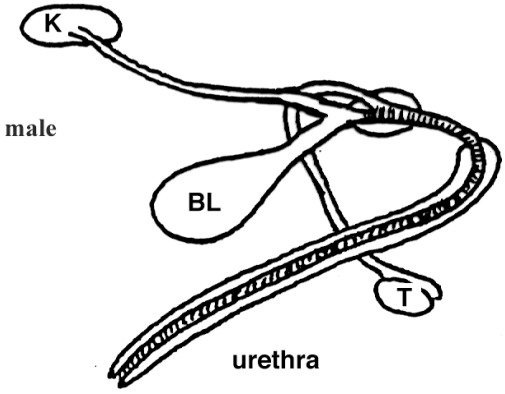
Urethra:

- A single tube that extends caudally from the neck of the bladder.
- In the female is intrapelvic only and lies ventral to the cervix and vagina.
- In the male has an intrapelvic part and an intrapenile part.

- As a result of having embryonic origins in common, elements of the male and female reproductive tracts are shared with parts of the urinary tract:
- In the female, the urethra opens into the vestibule, which is the common terminal part of both the urinary and reproductive tracts.
- In the male the two deferential ducts that carry sperm from the R and L testis empty into the pelvic part of urethra. Ducts of the accessory glands also open into the pelvic urethra.



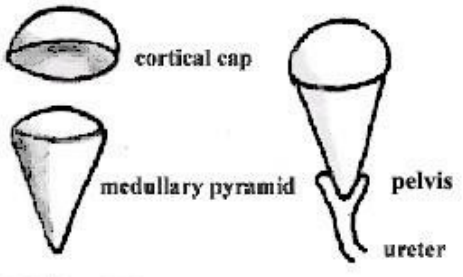

female



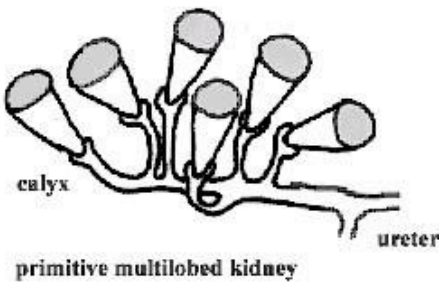

## The kidney

- The form is essentially a bean shape with variations on this shape in different species. Each kidney has a cranial and caudal pole and dorsal, ventral, medial and lateral surfaces.
- Is enclosed in a **capsule** and further surrounded by varying amounts of fat. The capsule has an outer connective tissue layer and in most domestic sp (except cat) an inner smooth muscle layer. It continues into the sinus and is continuous with the adventitia (connective tissue) covering the renal pelvis. It is easily removed from the surface of the healthy kidney.
- The **hilum** is the opening located on the medial aspect of the kidney that permits passage of the ureter, blood vessels, nerves and lymphatic vessels into and out of the renal sinus.
- Within the kidney the ureter forms expansions designed to catch the urine - either:
  A single **renal pelvis**: a single funnel shaped structure.
  Branches and at the end of each branch forms a cup like structure – the **calyx**
  A pelvis that then branches with calyces at the end of each branch.
- The **renal sinus** is the cavity within the kidney that contains the pelvis and/or calyces and the vessels and nerves. These structures are surrounded by fat within the sinus.

**The renal lobe:**
The renal lobe is the basic structural unit of the kidney (grossly). The renal lobe comprises a cap of cortical tissue and a pyramidal shaped portion of medullary tissue. The cortical cap sits on the base of the medullary pyramid. The apex of the medullary pyramid is referred to as the papilla, which projects into a pelvis or a calyx, depending on kidney type. Blood is filtered within the cortex and the filtrate is concentrated within the medulla. Urine drains from the medulla, via openings located at the tip of the papilla, into a calyx or pelvis.




single kidney lobe

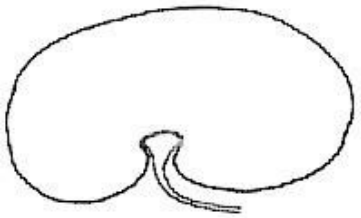



primitive multilobed kidney

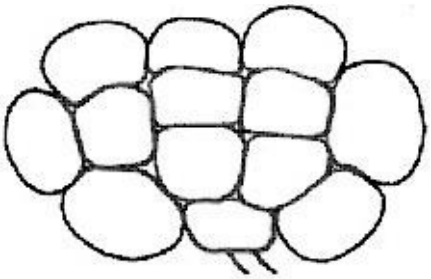
Most mammal kidneys have more than one lobe. In its most primitive form, a multilobar kidney is as depicted above, comprising many of these simple lobes joined together to form the organ.

**Classification of kidneys**

1. **Unilobar**
   - unipyramidal medulla
   - the apex of medulla forms a single papilla that faces into a single cup-shaped pelvis
   - rodents, rabbits



2. **Multilobar, lobes distinct**
   - lobation is apparent on the surface of the kidney
   - no or limited fusion of cortical and medullary components
   - multipyramidal
   - calyces and no pelvis

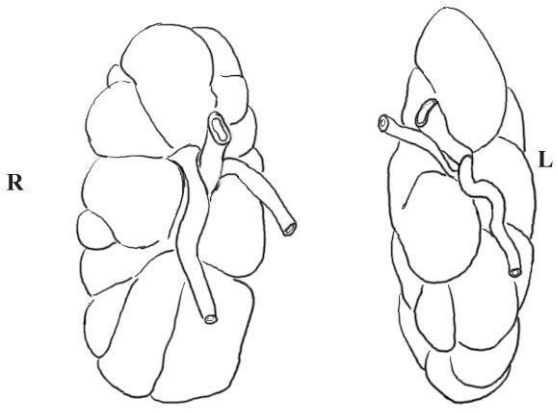


Is the closest to the primitive multilobar type amongst the domestic animals. There is some fusion e.g. 2-5 medullary pyramids may share a common cortex and calyx.

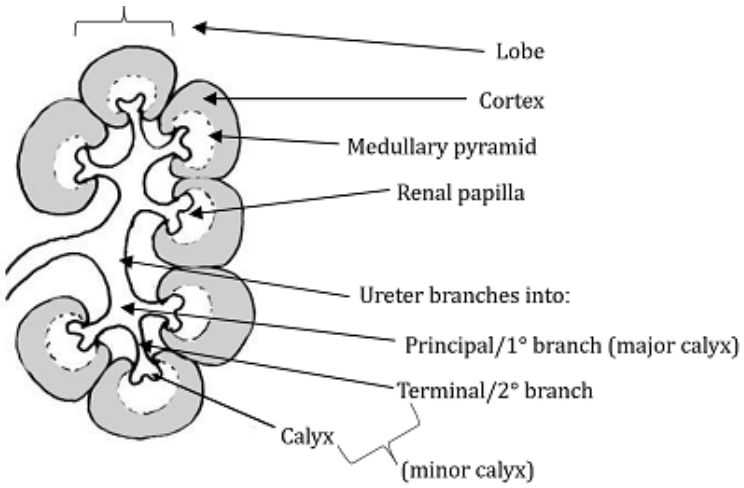
Ox:

- right kidney - flat oval shape; left kidney– pyramidal/slightly pear shaped: caudal pole larger than cranial pole and is slightly twisted
- red brown and has considerable perirenal fat
- has 12-25 lobes that very in size: smaller =1 lobe, larger =fusion of 2-5 lobes
- the surface of the kidney has deep fissures between adjacent lobes or fused lobes
- right kidney is cranial to left and has cranial pole projecting into renal impression of liver; left kidney more pendulous and mobile - is usually pushed to the right of midline by the rumen
- distinct medullary pyramids & papillae.
- The ureter branches into two principal or primary branches (sometimes called major calyces) that further branch into terminal/secondary branches. Each terminal branch expands to form a calyx that surrounds the papilla (the calyx + its branch also referred to as the minor calyx). There is no pelvis

3. **Multilobar, cortical fusion only**



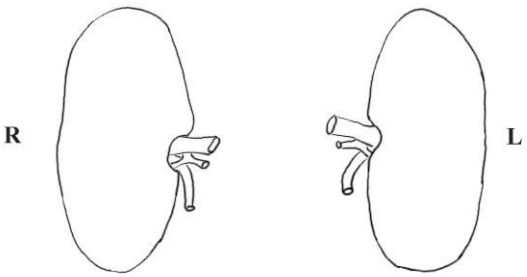

right (R) and left (L) kidneys of the ox (ventral aspect)



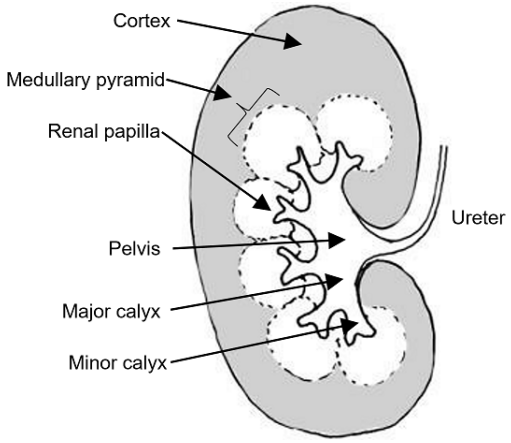

- The surface is smooth due to cortical fusion so there is no external indication of lobation
- Internally the medullary pyramids and pyramids are distinct indicating lobation
- Has calyces arising from a branched pelvis

Pig:

- The kidneys are brown and left & right kidneys are a similar shape - dorsoventrally flattened, elongated, ovoid bean shape
- both kidneys usually lie ventral to the transverse processes of the first 4 lumbar vertebrae. The left may be quite variable in position but is often slightly cranial to the right
- typically have no contact with liver
- may have considerable perirenal fat
- Single pyramids with single narrow papilla or fusion of 2-5 adjacent pyramids to form an aggregate papilla
- Pelvis has central cavity with 2 recesses (major calyces) and bears the minor calyces either directly or on short branches. Papillary ducts at apex of papillae drain into each minor calyx



right (R) and left (L) kidneys of the pig (ventral aspect)




**4. Multilobar – cortical and medullary fusion (crest type)**

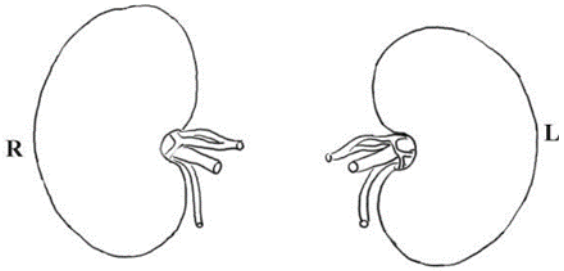
- Is bean shaped with no visible lobation externally so has a smooth surface
- Colour varies depending on species
- Hints of the original lobation can be seen internally – these include the arrangement of the blood vessels and also the presence of regular undulations in the corticomedullary junction indicating the original demarcation between adjacent medullary pyramids
- The extensions of cortical tissue into the medulla between the bases of adjacent medullary pyramids are called **renal columns**
- Has a pelvis with **pelvic recesses** – expansions of the pelvis that are modified calyces
- The medullary pyramids are fused so that the medullary margin facing the pelvis forms a longitudinally oriented ridge or **crest** along the median plane.
- In some species the recesses project from the border of the pelvis at spaced intervals along either side of the midline. The medullary tissue dips down between each recess to form **pseudopapillae** – i.e. not true papillae as they have no papillary duct openings
- Dog, cat, horse, goat, sheep

**Typical crest type:**

- dog, sheep, goat
- typical bean shape, smooth surface
- right kidney cranial to left & cranial pole of right kidney in renal impression of liver

Dog:

- brownish red to bluish red colour
- size/weight breed dependent
- soft perirenal fat - amount depends on body condition, thin to absent on ventral surface
- location: R: cranial pole: rib 12-13, caudal pole: L2-3 L: sl. more caudal than R, more mobile.
- both kidneys palpable through abdominal wall
- stellate veins over surface - may be hard to distinguish



right (R) and left (L) kidneys of the dog (ventral aspect)

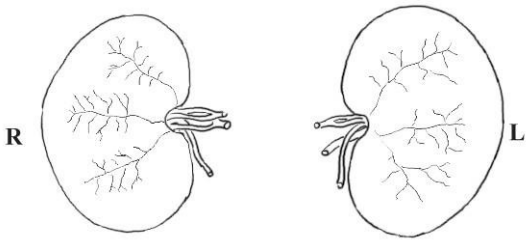
Sheep & goat:

- brown, bean shape, difficult to distinguish sheep from goat (hilum deeper in sheep, kidney thinner and longer in goat)
- left kidney pendulous and mobile – located to right of median plane /dorsal sac of rumen – may have flattened left surface in contact with rumen,
- large amount of perirenal fat – fat firm (hardens when cold) and white cf. dog
- Shape of pelvis, pelvic recesses and pseudopapillae similar to dog

**Variations of crest type:**

Cat:

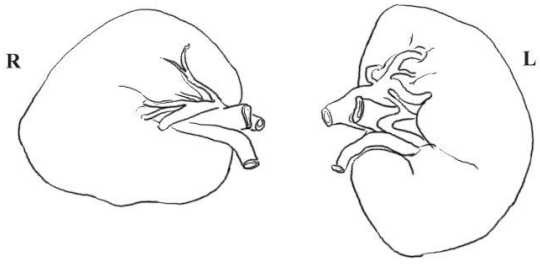
- light or dark yellow-red, typical bean shape
- rounder shape than dog or sheep
- more caudal than in dog - both kidneys palpable
- Location R: ventral to L1-L4 transverse processes
  L: ventral to transverse processes of L2-L6 and more mobile
- distinct capsular veins on surface; converge towards hilum to drain via renal vein
- perirenal fat as described for dog
- internal structure including shape of pelvis similar to dog



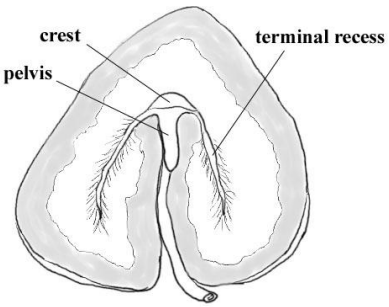
right (R) and left (L) kidneys of the cat (ventral aspect)

Horse:

- red brown, flattened dorsoventrally
- right – shaped like the heart on a playing card; left – more elongated bean-shape -form variable
- deep hilum on ventral surface at medial border
- R kidney: Rib 15-17 to first lumbar vertebra, cranial pole contacts the renal impression of liver.
- L kidney: Rib 16-18 to L2-3 – more mobile, occasionally lies completely caudal to last rib
- soft yellow perirenal fat, less fat than seen in ruminants and pig
- small renal crest & pelvis papillary ducts from central part of kidney open here
- long terminal recesses extend towards each pole - papillary ducts also open here



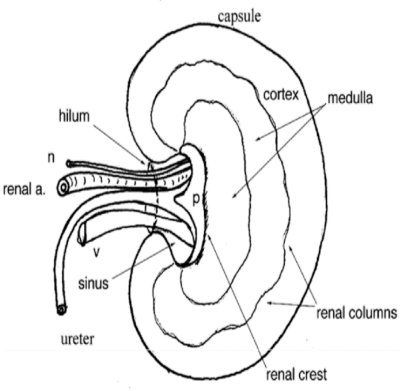
right (R) and left (L) kidneys of the horse (ventral aspect)



sectioned kidney showing terminal recesses

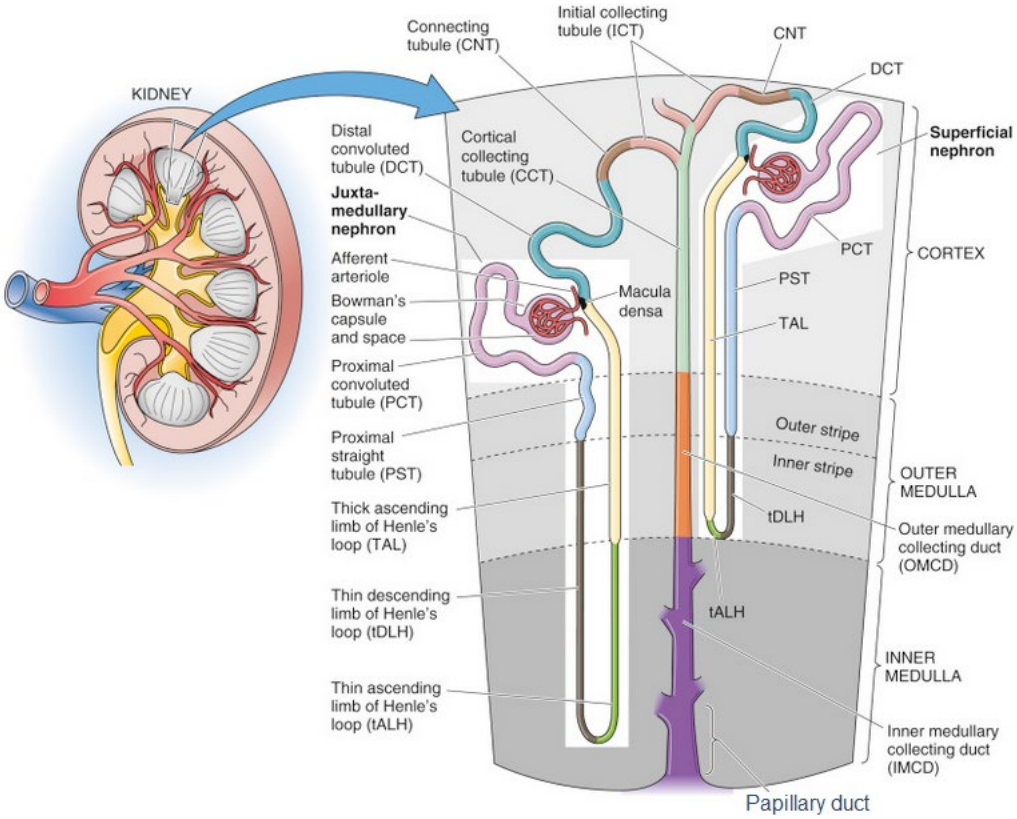
**Macroscopic internal organisation of crest type kidney – median section:**

- Outer region: **cortex**: red brown with granular appearance of cut surface
- Inner region: **medulla**: outer purple zone and inner paler zone, with radially striped appearance
- Smooth **renal crest** formed by fusion of renal papillae in the median plane
- The corticomedullary junction appears scalloped due to the **renal columns**: extensions of cortical tissue between the bases of adjacent fused medullary lobes



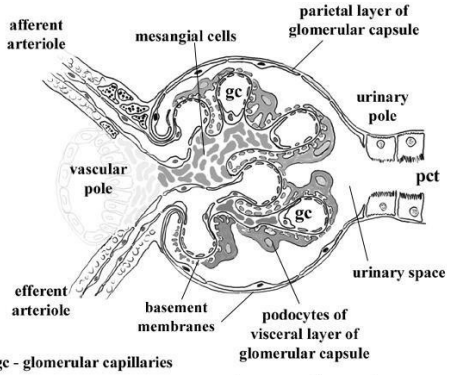

The macroscopic appearance of the cut surface of the kidney results from the structure of the nephron and arrangement of the renal blood vessels.

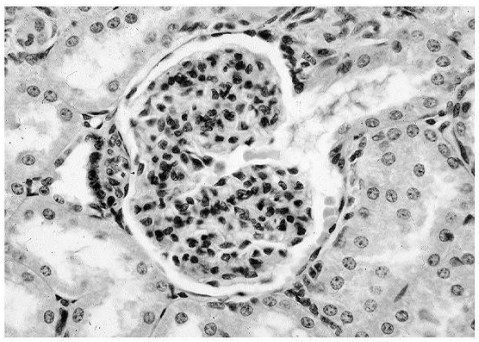
**The nephron:**
The functional unit of the kidney that filters blood and forms urine. It starts at the renal corpuscle.

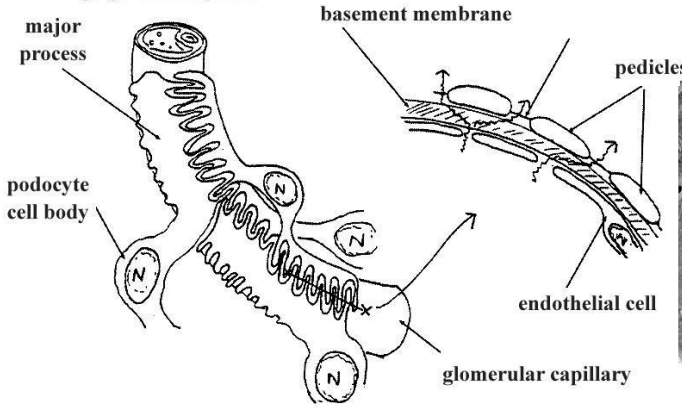


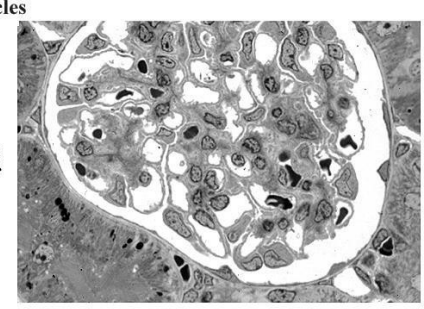

**The renal corpuscle:**

- comprises the glomerulus – a spherical structure composed of loops of porous capillaries, enclosed within the glomerular or Bowman's capsule - the dilated initial part of the nephron.
- mesangial cells surround and support the capillaries
- is the location where blood is filtered in the first stage of urine formation
- At the vascular pole: blood flows from the afferent arteriole into glomerular capillaries, leaves via the efferent arteriole





- The glomerular capsule comprises 2 layers of epithelium (parietal and visceral) that are continuous at the vascular pole. Opposite this pole is the urinary pole where the outer layer of the capsule is continuous with the epithelium of the first part of the tubular part of the nephron (the proximal convoluted tubule -PCT). Between the two epithelial layers is the urinary space (Bowman's space) into which the blood filtrate enters. This space is continuous with the lumen of the PCT.
- The filtration barrier between the capillary and the urinary space is formed by:
    - Fenestrated (porous) capillary endothelium
    - Basement membrane
    - Podocytes of visceral layer of glomerular capsule: located on surface of capillaries: foot processes (pedicles) of adjacent podocytes interdigitate to form filtration slits that are bridged by a filtration membrane

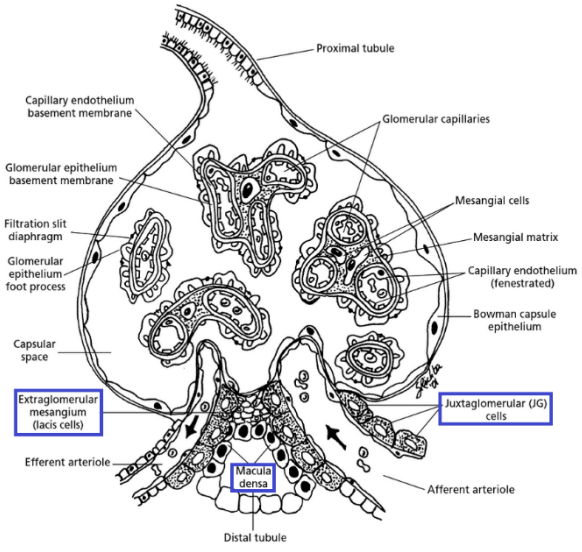
**Tubular part of the nephron:**
Continuing from the glomerular capsule is the tubular part of the nephron that is divided into distinct segments. The structure and location of these segments contributes to the differences in gross appearance and function between the cortex and different regions of the medulla.

Proximal convoluted tubule - comprises a large portion of the cortical labyrinth (see later) ⟶
Proximal straight tubule/descending thick limb of the loop of the nephron (loop of Henle) ⟶
Descending thin limb of the loop of the nephron (loop of Henle) ⟶ hairpin bend
Ascending thin limb of the nephron (loop of Henle) ⟶
Distal straight tubule/ascending thick limb of loop of the nephron (loop of Henle) ⟶
Distal convoluted tubule ⟶
Connecting tubule and initial collecting tubule ⟶
Straight collecting duct: descends towards renal papilla through cortex and medulla ⟶
Papillary Duct: the collecting ducts merge as they descend through the medulla to form the papillary duct. The papillary ducts open at the tip of the papilla or on renal crest (cribriform area).

Nephrons are classified according to location of renal corpuscle and length of Loop of Henle:
Superficial nephron: corpuscle located closer to outer cortex, short loops that lack a thin ascending limb and only penetrate outer part of medulla
Juxtamedullary nephron: corpuscle near junction of cortex and medulla, long loops with thin ascending limb penetrate deep into the medulla. Long loops are associated with the capacity for countercurrent exchange with capillaries of the vasa recta (see below) and the production of concentrated urine
Midcortical nephron: corpuscle located midway between superficial and juxtamedullary glomeruli - may have a short or a long loop
In general, animals with a greater ability to produce concentrated urine have a greater percentage of long loop nephrons. E.g. ratio of long to short: rodents 3:1 vs human 1:7

**The juxtaglomerular apparatus:**
Located at the start of the distal convoluted tubule where it meets the vascular pole of the renal corpuscle of its own nephron. Is involved in blood pressure regulation, control of renal blood flow and glomerular filtration rate. Is composed of:
Juxtaglomerular cells:

- specialized smooth muscle cells in wall of afferent arteriole
- act as baroreceptors and secrete renin when blood pressure in the afferent arteriole falls.
- renin acts to increase blood pressure via the renin-angiotensin system
- renin secretion influenced by the macula densa, also stimulated by sympathetic nerve activity



The macula densa:

- Dense epithelial cells at the junction of the distal straight tubule and the distal convoluted tubule
- Act as chemoreceptors for NaCl concentration in the tubular lumen. (Also sense other signals)
- In response to increased NaCl trigger arteriolar vasoconstriction, reducing blood flow to glomerulus and decreased glomerular filtration rate.
- Influence renin secretion by juxtaglomerular cells (⬆renin with ⬇NaCl, ⬇renin with ⬆NaCl).

Extraglomerular mesangial cells:

- Cells located between the afferent and efferent arterioles and between the macula densa and vascular pole, just outside the glomerulus.
- Functions not well understood – also produce renin and are thought to have a role in regulating renal blood flow and systemic blood pressure through the renin-angiotensin system

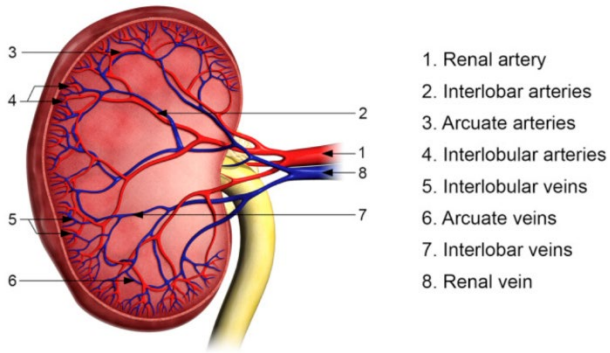
**Major blood vessels of the kidney:**

Arterial supply:

- **Renal artery**: from abdominal aorta, major branches in region of hilum.
- **Interlobar arteries**: arise from branches of renal a. Radiate towards cortex between medullary lobes. In the region of the corticomedullary junction each interlobar a gives rise to several:
- **Arcuate arteries**: follow the curvature of the base of the medullary pyramids and give rise to the:
- **Interlobular arteries**: radiate through the cortex to the capsule and on their way give off the:
- **Afferent arterioles**: pass to the vascular pole of the renal corpuscle to branch into the capillaries of the **glomerulus**
- Blood leaves the glomerulus via the **efferent arteriole** to branch into a c**apillary** network that surrounds nephron tubules within the cortex
- **Straight arterioles** (**descending vasa recta**) arise from efferent arterioles of juxtamedullary glomeruli (= 'false straight arterioles') or from arcuate and interlobular arteries (= 'true straight arterioles'). These form capillary networks around the straight tubules within the medulla – participate in countercurrent exchange with the loops of the nephron.

Venous drainage:

- Cortex: cortical capillaries (directly or via **interlobular veins**) ⟶ **arcuate veins** ⟶ **interlobar veins** ⟶ **renal vein**
- Medulla: capillaries ⟶ straight venules (**ascending vasa recta**) ⟶ arcuate veins ⟶ interlobar veins⟶ renal vein
- Capsule: capsule capillaries in most species ⟶ **subcapsular/stellate veins** (radiating star like branching) on surface of kidney ⟶ via interlobular ⟶arcuate ⟶interlobar veins ⟶ renal vein. In cat: capsular veins drain directly to renal vein.
- Renal vein drains to caudal vena cava

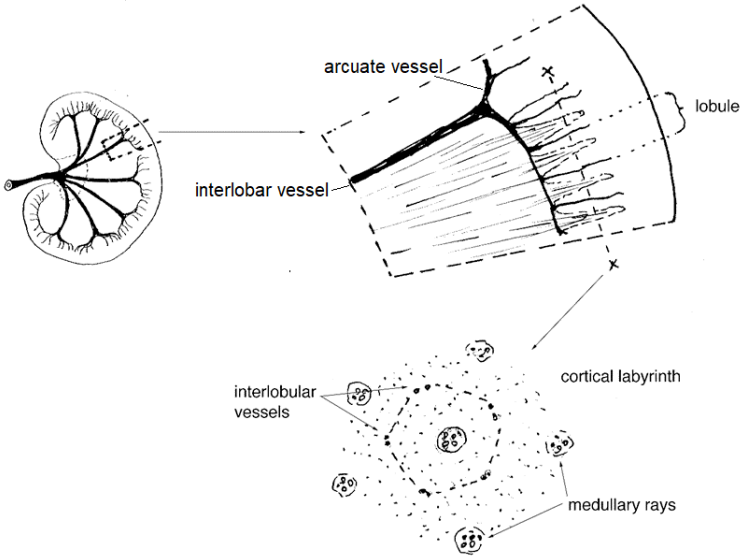


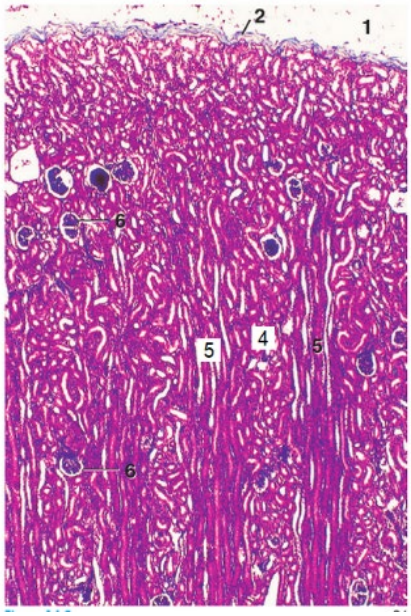

**Arrangement of the cortex:**

The renal cortex can be seen to be composed of subdivisions called **lobules**.
A lobule comprises a medullary ray surrounded by the cortical labyrinth

- **Medullary rays** are groups of parallel straight tubules running through the cortex from the medulla towards the capsule. The structure of the ray mimics that of the renal medulla, that consists of similarly organised straight tubules. The tubules of the medullary ray of one lobule comprise the straight tubules of all the nephrons surrounding and supplying a single collecting duct.
- **The cortical labyrinth** surrounds the medullary ray and consists of the convoluted tubules and renal corpuscles. The cortex has a granular appearance due to the presence of these structures.
- Interlobular arteries arise from the arcuate arteries and indicate the boundaries of the renal lobules.

- No indication of lobulation within the medulla as it is composed of straight tubules and ducts only.




Cortex, Dog: 4= cortical labyrinth 5 = medullary ray

## Urinary passages and storage organ:

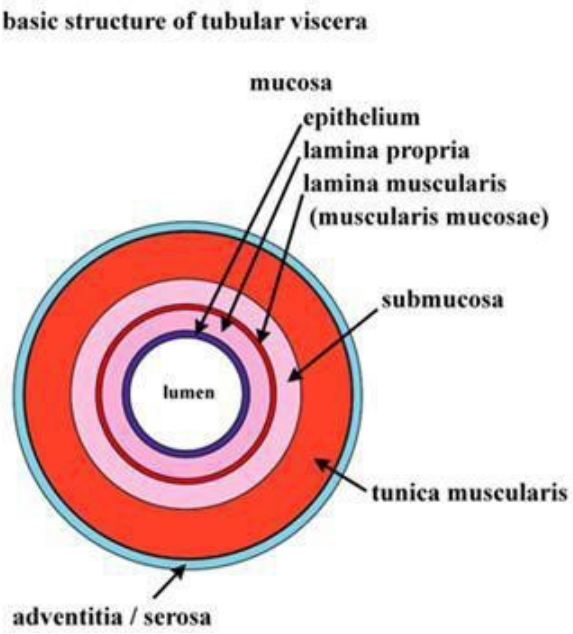
(=renal pelvis to external urethral orifice)

Basic structure - internal to external:

- Transitional epithelium throughout, except at terminal urethra
- Lamina propria/lamina muscularis/submucosa
- Tunica muscularis
  Smooth muscle only until pelvic urethra
- Adventitia or serosa on outer surface depending on the location of the structure

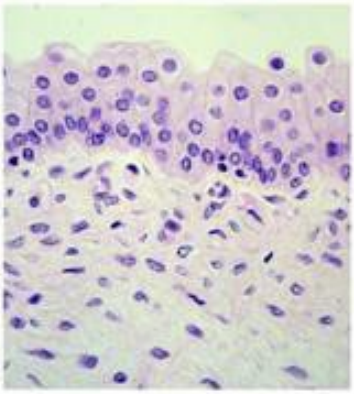
Adventitia: the outermost connective tissue covering of an organ, vessel or other structure

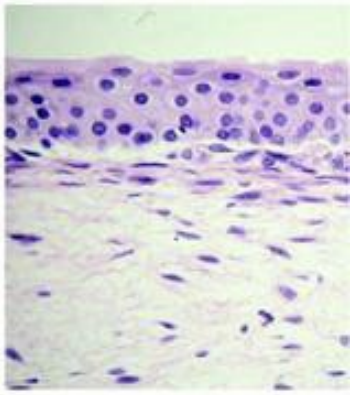
Serosa: lines body cavities – is connective tissue with a surface layer formed by simple squamous epithelial cells




### Transitional Epithelium

- Impermeable to urine, so prevents toxic wastes from entering bloodstream
- Maintains its integrity under tension / expansion -allows organ to stretch while retaining impermeability
- Lines all of the urinary tract except the terminal urethra, which is stratified squamous epithelium
- 3-4 layers of cells – the cells in the superficial layer are able to change shape from a rounded cuboidal shape to flattened squamous shape as the organ fills and the wall is stretched
- All cells are anchored to the basement membrane and connected to each other by junctional complexes – these hold the cells together so the epithelium always presents an uninterrupted surface to the lumen of the organ





- Apical membrane of the surface cells is covered by a network of thickened areas - protein plaques that contribute to the barrier to permeability. These plaques fold together when the organ is empty but spread apart as the organ is distended – so also contribute to the capacity for the superficial cells to change shape.

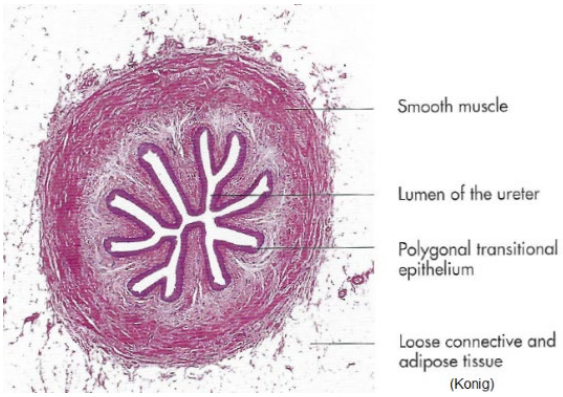
**Renal Pelvis and Calyces**

- Expanded portion of proximal ureter within the renal sinus – usually surrounded by fat
- Transitional epithelium
- Lamina propria/submucosa of loose connective tissue
- Tunica muscularis of three distinct layers
- Adventitia blends with that of the renal capsule and proximal ureter

In the horse: mucous glands are present in the submucosa of the renal pelvis and proximal ureter. Urine has a mucoid appearance and gives positive protein reaction on test.

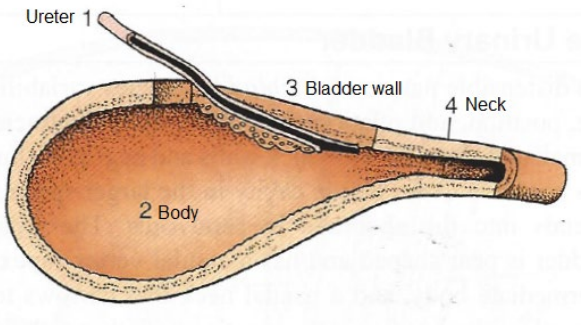
**Ureter**

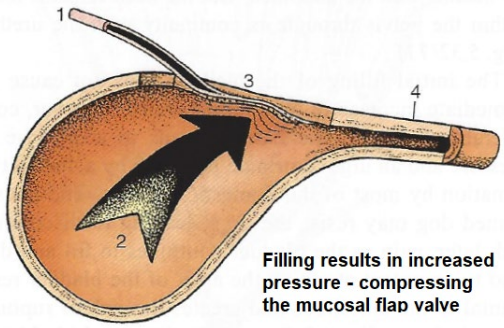
- Small, but thick walled, muscular tube
- Propels urine into the bladder by peristalsis
- The lumen appears stellate in cross-section due to longitudinal folding of the mucosa
- Transitional epithelium
- Lamina propria/submucosa of loose connective tissue and elastic fibres
- Tunica muscularis of 3 distinct layers -inner and outer are longitudinal fibres, middle layer circular fibres
- Usually embedded in fat, lies dorsal to serosa (retroperitoneal) until it descends towards the bladder




Location:

- Initially along roof of abdominal cavity, descends via the uterine broad ligaments (female), dorsal to the ductus deferens (male) and finally between serosal layers of lateral ligaments of the bladder.
- Enters the dorsal aspect of bladder either side of the midline and passes obliquely through the wall creating a mucosal-flap valve, which prevents reflux of urine into the ureters.



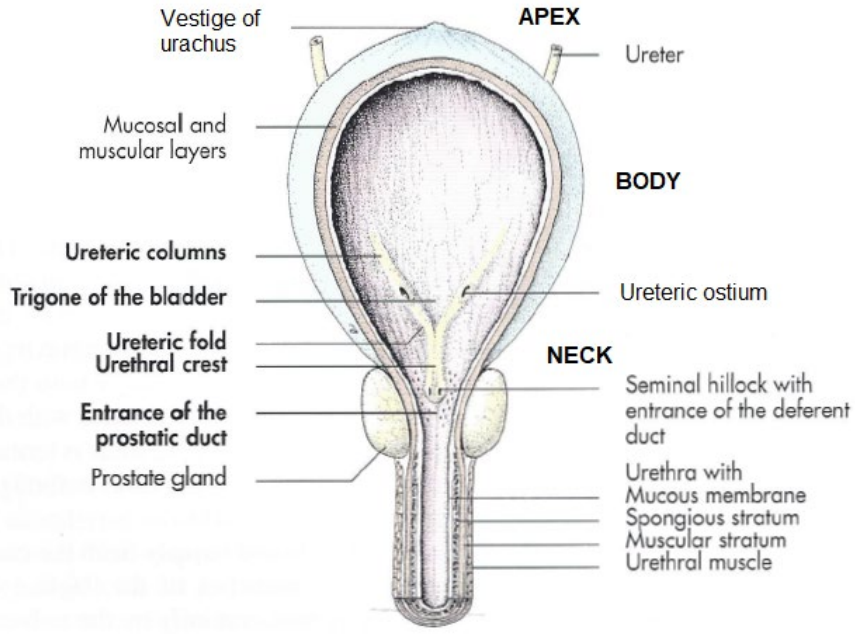




**Urinary bladder**

The urinary bladder is a highly distensible muscular storage organ with an apex (cranial blind end), body (main portion) and neck (narrow caudal part) - the neck leading into urethra.

Structure:

- Transitional epithelium
- Lamina propria and submucosa are distinct due to a difference in weave of the connective tissue
- A muscularis mucosae of isolated fascicles may be present (not in sheep or cat)
- Tunica muscularis (also called the <u>detrusor</u> muscle) – has three layers but these interweave with eachother – so not distinct
- Serosa covers the surface of the apex and most of body, adventitia covers the most caudal part of the body and the neck.

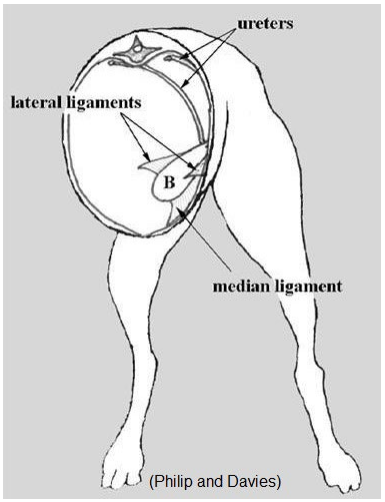



Interior of bladder of male dog from ventral aspect (Konig)

The ureters enter the bladder laterally and dorsally and run under the mucosa within mucosal ridges – the **ureteric columns**. Beyond the ureteric openings these ridges continue as the **ureteric folds** that converge towards neck of the bladder and meet to form the **urethral crest**, which extends on the dorsal mucosal surface of the proximal urethra for a short distance.
The **trigone** is the triangular area bounded by the ureteric openings of both sides and the converging ureteric folds.

Bladder ligaments:
The bladder is stabilised by three ligaments that extend to the abdominal and pelvic walls. The ligaments attach to the body and neck region, leaving the apex of the bladder free to permit expansion.

- **median ligament** extends from the ventral midline of the bladder and attaches in the region of the linea alba as far cranially as the umbilicus
- l**ateral ligaments** originate on the lateral aspect of the caudal body and neck. The round ligaments of their cranial margins are remnants of the foetal umbilical arteries




The urachus is present during foetal life. It is a tube that extends from the apex of the bladder and through the umbilical cord, that carries urine to one of the placental sacs. It closes over before birth. A vestige of this structure may be visible at the centre of the apex of the bladder and may extend along the median lig.

**Urethra**

The urethra is a muscular tube beginning at the bladder neck and extending caudally on the floor of the pelvis (and through the penis in the male) to the external urethral orifice, which opens within the vestibule (female) or at the distal extremity of the penis (male).
In the male, the ductus deferens (carries sperm and seminal fluid from the testes) and the accessory glands (contribute further to seminal fluid) open into the pelvic urethra.

Structure:

- Transitional epithelium except at its termination, which is stratified squamous epithelium
- Lamina propria/submucosa of loose connective tissue containing large blood channels – this

cavernous tissue = corpus spongiosum –small amount in pelvic urethra in both female and male and in the male is significantly expanded within the penis – contributes to erectile function.
- Rudimentary muscularis mucosa
- Tunica muscularis consists of smooth muscle (generally 3 irregular layers) through length of urethra. Skeletal muscle – the urethralis muscle. (longitudinal and circular layers) surrounds the smooth muscle of the intrapelvic urethra from just distal to the bladder neck.
- Adventitia forms the outer connective tissue layer

Suburethral diverticulum:
- Present in cow and sow
- Urethra opens into the roof of a small diverticulum of the floor of the vestibule (female).

Os penis
- Present in many mammalian species including carnivores and rodents, but not ungulates (hoofed animals and cetaceans) – is a splanchnic bone (within soft tissue and not attached to skeleton)
- In the dog is grooved ventrally to accommodate the urethra and because it partly surrounds the urethra can cause lodgment of urinary calculi (stones) within the urethra.
- Does not have a ventral groove in the cat although urethral obstruction in male cats is quite common for other reasons.

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