Histology of the Kidney and Urinary System

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The kidneys are located in the lumbar region, on either side of the vertebral column, and just outside of the dorsal peritoneum.
The renal arteries arise from the abdominal aorta. The kidneys have one of the greatest blood flows of any organ in the body.

Together, they receive 1/4 to 1/5 of the blood ejected by the heart each minute.
The kidneys maintain the blood at:

Constant volume.

Constant Ionic composition

Constant pH (unlike the blood which stays at a pH of about 7.4, urine can vary from pH 4.6 to 8.0)

The kidneys are the chief excretory organs for metabolic waste products, eg. Urea

They eliminate many drugs, pesticides and food additives
**Kidney Cross-section**

RC, renal column; OM, outer medulla; IM, inner medulla; VR, vasa recta; P, papilla; AV, arcuate veins; IV, interlobular veins
Drawing of a kidney cross-section
Diagram showing the parts of the nephron, and their disposition in the cortex and medulla.
Papillary collecting ducts (in orange) open on a minor calyx lined by transitional epithelium. Note the thin loops of Henle (green) and the vasa recta (red).
Every minute, 125 ml of ultrafiltrate is formed, yet only 1 ml of urine is excreted.

In the proximal tubule, 80% of the water and salts are returned to the body.

The thin limbs don’t have ion pumps, but differ in their permeabilities.
In the thick ascending limb, NaCl is actively pumped out into the surrounding interstitium, but water cannot follow. Thus, the tubule fluid becomes hypotonic.

In the collecting ducts, ADH (anti-diuretic hormone) causes aquaporin channels to surface, making the walls water-permeable.

Water can then leave the ducts, thus concentrating the urine.
The Renal Corpuscle consists of the glomerulus and the capsule around it
The three major types of capillaries, and where they are found

- Continuous
  - muscle
  - muscle
  - CT
  - CNS
  - lung tissue

- Fenestrated
  - endocrine organs
  - kidney glomeruli

- Discontinuous (sinusoidal)
  - liver
  - bone marrow
  - spleen
The parietal layer of Bowman’s capsule is continuous with the visceral layer overlying the glomerular capillaries.
Electron Micrograph of a renal corpuscle

Glomerular capillary containing a lymphocyte

Filtration barrier

Podocyte
SEM of a glomerular capillary covered by a podocyte and its processes and pedicels.

Podocytes reveal the most complex and spectacular epithelial-epithelial interactions in the body.
Podocytes sit atop the glomerular basement membrane
SEM of a glomerular capillary covered by the processes and pedicels of a podocyte.
SEM of glomerular capillaries covered by the processes and pedicels of podocytes. A glycoprotein, podocalyxin, coats the podocyte surface and contributes to the negative charge of the visceral surface.
Mesangial cells

Structures and cells within the renal corpuscle
Mesangial cells:

- Can contract and relax and can thus modify glomerular filtration
- Aid in production and breakdown of the basement membrane
- Respond to local injury by proliferation and basement membrane remodeling - as in diabetes and some forms of glomerulonephritis
PAS stain of the renal corpuscle and surrounding tubules; mesangial cells within the corpuscle surround themselves with a PAS positive substance.
The basal lamina is 320-340 nm thick - the thickest in the body.
Glomerular Filtration Barrier
Immune Glomerulonephritis - thickening of basement membrane

Membranoproliferative Glomerulonephritis - thickening of basement membrane and mesangial cell proliferation

Minimal Change Glomerular Disease - irregular podocyte foot processes
In Minimal Change Glomerular Disease, the podocyte foot processes and pedicels have disappeared.
In Immune Glomerulonephritis, glomerular damage can often be attributed to processes of immunologic origin, involving antibody formation, for example:

1. Antigen-antibody complexes may be formed in the body as the result of a bacterial infection, or they may be endogenous, resulting from an autoimmune disease (such as lupus). These complexes may then become trapped and deposited on the basement membrane and elsewhere in the glomerulus, causing damage.
2. Circulating foreign molecules may interact with parts of the filtration barrier to create a new and novel antigen, which the body now recognizes as foreign. This can induce antibody formation leading to subsequent injury.

3. In auto-immune disease, auto-antibodies may be directed against parts of the glomerulus itself, leading to damage.
62,000 MW Dextran (black particles) is substantially retained in the glomerular capillary; just a few particles escape into the urinary space (US).
Bowman’s capsule opens into the proximal tubule at the urinary pole of the renal corpuscle.
Scanning EM of a proximal tubule
80% of water and salts are reabsorbed

All glucose is reabsorbed

Amino acids and proteins are reabsorbed

Certain organic acids and bases are secreted into the tubule

Na enters the tubule cell via Na channels, co-transporters or exchangers, and is pumped out of the basal and lateral borders.
EM of a Proximal Tubule Cell
Myoglobin (16kD) has leaked through the glomerular filter and is being pinocytosed and subsequently degraded by a proximal tubule cell.
Interdigitating cells of the proximal tubule
Figure 31-18  Electron micrograph of the abrupt junction of the straight portion of the proximal tubule with the thin limb of the loop of Henle. Slightly oblique section through the junction. The brush border stops suddenly and the epithelium becomes very thin. × 4200. (After Osvaldo and Latta, J. Ultrastr. Res., 15:144, 1966.)
Thin loop of Henle (1) leading to thick ascending limb (2) via a hairpin turn (3); peritubular capillaries of differing diameters (5)
Cells lack a brush border

Abundant mitochondria and membrane infoldings

Content becomes hypotonic as salt is pumped out, but water cannot follow

Thick Ascending limb of Henle’s loop
Distal Tubule cells are responsive to aldosterone, a steroid secreted by the Z. glomerulosa of the adrenal cortex.

Na+ is reabsorbed into the body, and K+ is excreted into the tubule fluid here.

Hydrogen and ammonium ions are secreted into the tubular urine, thus aiding in the maintenance of the acid-base balance of the blood.
Comparison of distal and proximal tubule cross-sections in the cortex.
Macula Densa Cells

Sense the ionic content and water volume of the tubular fluid.

Influence the glomerular filtration rate

Can affect blood pressure by stimulating renin secretion

Can cause vasodilation via their synthesis of nitric oxide.
Figure 22-30  Electron micrograph of a medullary collecting tubule from a normal human kidney. Medullary collecting cells are
Collecting ducts are the major components of the pale-staining medullary rays.
Cortical medullary rays seem to radiate from the medullary pyramid. The apex of the renal medullary pyramid is lodged in the cup-like calyx.
Collecting ducts consist of principal and intercalated cells.

Principal cells become permeable to water (under the influence of ADH) by shuttling aquaporin water channels from the cytoplasm to the apical membrane.

It is by means of this property that urine can be concentrated.

Intercalated cells can secrete or resorb protons, depending on body needs.
Diseases Affecting Kidney Tubules and the Tissues Between Them (Interstitium)

The two major causes of damage to the tubules and interstitium are:

1. Bacterial infection: Pyelonephritis

2. Injury due to toxic drugs or metabolic disorders: Interstitial nephritis (Ibuprofen and other NSAIDs (Non-steroidal anti-inflammatory drugs) can cause kidney damage.
Blood Pressure Control - Juxtaglomerular Apparatus

Juxtaglomerular apparatus: J-G Cells, Macula densa, Mesangium
**Juxta-glomerular cells (J-G cells)**

Location in wall of afferent arteriole as it approaches the glomerulus.

J-G cells are myo-epithelioid (modified smooth muscle) and store the enzyme, renin, in cytoplasmic granules.

J-G cells are adjacent to "macula densa" cells of distal tubule and communicate with them via gap junctions.
Macula densa
**Macula Densa**

Part of distal tubule, where it contacts glomerulus

Cells more numerous and columnar in this area

Macula densa cells come in close contact with the afferent arteriole of the glomerulus, and communicate with the JG cells in its wall.

Macula densa cells sense changes in osmolarity and volume of tubule fluid, and can influence glomerular filtration rate and J-G cells' renin secretion.

They synthesize NO, and can thus cause vasodilation.
• A decrease in blood pressure in the afferent arteriole stimulates the J-G cells to secrete the proteolytic enzyme, renin.
• Renin encounters angiotensinogen, a protein made by the liver and circulating in the blood.
Renin converts angiotensinogen to Angiotensin I (an inactive decapeptide).
Angiotensin I converting enzyme (ACE) located in endothelial cells of the lung and elsewhere, converts Angiotensin I to Angiotensin II, a vasoactive octapeptide.
Angiotensin II raises blood pressure in several ways:
1. It stimulates the pituitary to release antidiuretic hormone (ADH), also known as Vasopressin; this, in turn increases water resorption from the collecting tubules, which leads to increased blood volume and blood pressure.
Angiotensin II raises blood pressure in several ways:

2. It constricts arteriole walls → ↑ blood pressure
Angiotensin II raises blood pressure in several ways:

3. It stimulates secretion of Aldosterone from the adrenal gland, which in turn stimulates resorption of NaCl → ↑ blood volume → ↑ blood pressure
The renin-angiotensin-aldosterone system (RAAS) plays a crucial role in regulating blood pressure and electrolyte balance. The process begins with the release of renin from juxtaglomerular cells in response to decreased renal perfusion pressure or sodium depletion. Renin cleaves angiotensinogen to form angiotensin I, which is then converted by angiotensin-converting enzyme (ACE) to angiotensin II. Angiotensin II acts on the adrenal zona glomerulosa to stimulate aldosterone production, increasing sodium and water reabsorption in the distal nephron. Aldosterone, in turn, increases sodium reabsorption, leading to a decrease in sodium and water excretion by enhancing reabsorption in the proximal tubule. This feedback loop helps maintain blood pressure and sodium balance within the body.
Decreased blood pressure in the afferent arteriole stimulates baroreceptors in the J-G cells.

J-G cells secrete the proteolytic enzyme, renin.

Renin acts on angiotensinogen in the plasma.

Angiotensinogen is converted to Angiotensin I (an inactive decapeptide).

Angiotensin I converting enzyme (ACE) located in endothelial cells of the lung and elsewhere, converts Angiotensin I to Angiotensin II.
Angiotensin II raises blood pressure by:

1. Constricting arteriole walls → ↑ blood pressure

2. Stimulating secretion of Aldosterone which in turn stimulates resorption of NaCl → ↑ blood volume → ↑ blood pressure

3. Stimulating the pituitary to release antidiuretic hormone (ADH), also known as Vasopressin; this, in turn, increases water resorption from the collecting ducts → ↑ blood volume → ↑ blood pressure
Diagram to show the structure and blood supply of the kidney of man.
Renal Blood Vessels
Kidney Compartments

- Minor calyx
- Renal artery
- Renal Vein
- Ureter
- Renal Pelvis
- Major Calyx
- Renal columns (cortex)
- Renal pyramids (medulla)
- Renal cortex
- Medulla
URETERS EXPOSED FROM IN FRONT

DIAPHRAGM
R. SUPRARENAL GLAND
R. KIDNEY
R. RENAL ARTERY AND VEIN
R. SUBCOSTAL NERVE
TRANSVERUS ABDOMINIS MUSCLE
QUADRATUS LUMBOUM MUSCLE
ILIAC CREST
PSOAS MAJOR MUSCLE
ILIACUS MUSCLE
R. URETER
R. COMMON IliAC ARTERY
R. EXT. IliAC ARTERY
R. INT. IliAC ARTERY
URINARY BLADDER
L. SUPRARENAL GLAND
CELIAC TRUNK
L. KIDNEY
L. RENAL ARTERY AND VEIN
SUP. MESENTERIC ARTERY
SUBCOSTAL NERVE
AORTA
ILIOHYPOGASTRIC NERVE
ILIOINGUINAL NERVE
LATERAL FEMORAL CUTANEOUS NERVE
GENITOFEMORAL NERVE
L. TESTICULAR ARTERY AND VEIN
INF. MESENTERIC ARTERY
PERITONEUM
MESOSIGMOID
RECTUM