Chapter

The Development and Anatomy of Adrenal Glands

Ravi Kant Narayan, Ashutosh Kumar and Manika Verma

Abstract

The retroperitoneal adrenals are situated in the epigastric region of the abdomen, on the upper pole of either kidney. The glands are golden-yellow in color. The right adrenal is triangular or pyramidal, and the left one is semi-circular or crescentic in shape. The blood supply rate per gram of tissue for the adrenal gland is one of the highest. The two parts of the gland are derived from two different embryological tissues. This chapter discusses the normal macro- and microscopic anatomy of the gland along with its embryological development.

Keywords: adrenal, glands, retroperitoneal, microscopic anatomy, embryology

1. Introduction

The kidneys' fibrous capsule (renal fascia) wraps a wedged glandular and neuroendocrine tissue to its upper pole. These tissue masses are referred to as adrenal glands [1]. The adrenal glands were initially described in detail by Italian anatomist Bartolomeo Eustachi in 1563–1564. Adrenal is a Latin word where "*ad*" means "near", and "*ren*" means "kidney". The paired structure was termed "suprarenal", another Latin word where "*supra*" means "above", by Jean Riolan the Younger in 1629 [2]. These are endocrine glands, therefore, receive profuse blood supply via multiple arteries. In gross appearance, these are yellowish [3].

Adrenal glands have two major parts: the cortex and the medulla. These two parts share the similarity in their location, apart from which they differ in their ontogeny, phylogeny, architecture, and function [4]. In this chapter, the adrenals are discussed under the following headings:

1. Location, external features, & coverings

2. Gross appearance and microscopic architecture

3. Arterial supply, Venous & Lymphatic drainage

4. Nerve innervations

5. Development

2. Location, external features, & coverings

The retroperitoneal adrenals are situated in the epigastric region of the abdomen, on the upper pole of either kidney (**Figure 1**). The right adrenal being pyramidal in shape, has an apex, a base, two surfaces (anterior and posterior), and three borders (medial and

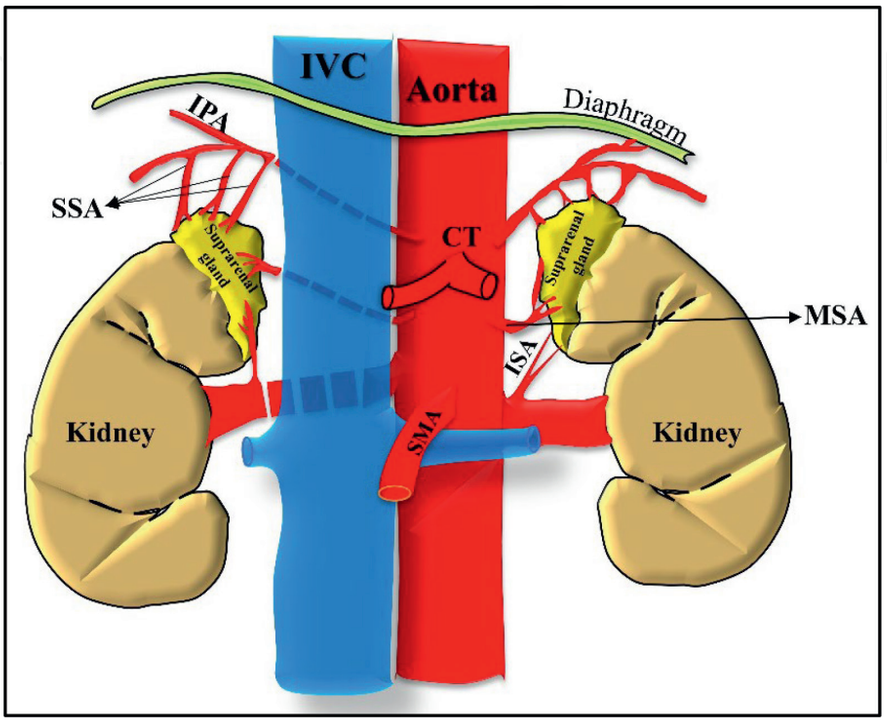

Figure 1.
Illustration of the adrenal/ suprarenal gland's location on the upper pole of both kidneys and the blood supply of the glands (IVC – inferior vena cava, IPA – inferior phrenic artery, CT – coeliac trunk, SMA – superior mesenteric artery, SSA – superior suprarenal artery, MSA – middle suprarenal artery, ISA – inferior suprarenal artery).

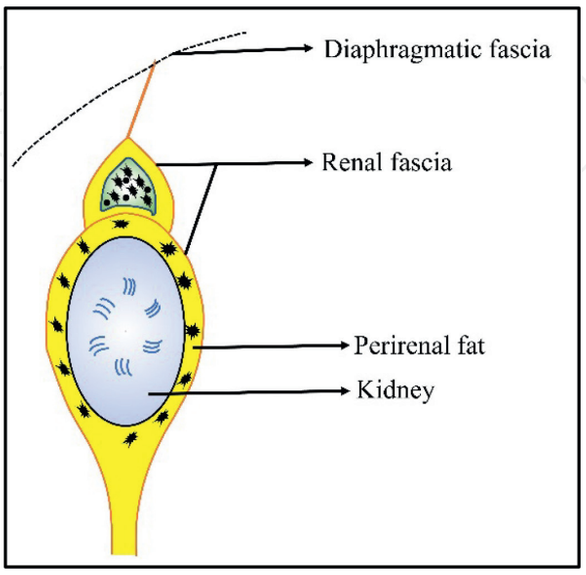

Figure 2.
Sectional illustration of the renal fascia enveloping the kidney, and adrenal gland, extending to fuse with the diaphragmatic fascia.

lateral) [4]. The posteromedial surface is related to the diaphragm, and the inferior vena cava is on the anteromedial surface. Different aspects of the liver are related to the right adrenal; the right lobe of the liver lies anteriorly, while the bare area is located superior to the gland. The right kidney's upper pole is inferolateral to the endocrine structure. The crescentic left adrenal has two ends (narrow upper end and rounded lower end), two borders (medial and lateral), and two surfaces (anterior and posterior). The stomach lies anteriorly, the diaphragm posteromedially, and the kidney inferolateral [1].

The adrenals are surrounded by two sheaths, a layer of loose areolar tissue directly encapsulating the glands, and is composed of a significant quantity of fat. At the same time, the outer layer is the continuation of renal fascia, which also forms a thin septum separating the kidney from the adrenal above. An extension of the fascia connects the adrenal capsule's outer layer to the diaphragm's underlying peritoneal layer, which is attributed to the movement of the gland during respiration (**Figure 2**) [5].

3. Gross appearance and microscopic architecture

The size of the adrenal glands is around 5 cm long, 3 cm wide, and up to 1 cm thick. They weigh about 7 and 10 grams together in an adult person. The glands are golden-yellow in color (**Figure 3**) [3]. The right adrenal is triangular or pyramidal, and the left one is semi-circular or crescentic in shape. The external yellow-gold adrenal cortex and the inner brown-red adrenal medulla could easily be demarcated by gross examination of the cut surface of the adrenal gland [1, 6].

Microscopically, the adrenal cortex can be divided into three separate zones depending upon the arrangement of the cells (**Figure 4**). These are zona glomerulosa, zona fasciculata and zona reticularis. Each zone produces specific hormones pouring into the sinusoids running between the cells [7].

3.1 Zona glomerulosa

This is the outermost zone of the cortex, located just underneath the fibrous capsule. The cells are arranged in oval clusters giving the term "glomerulosa". Aldosterone

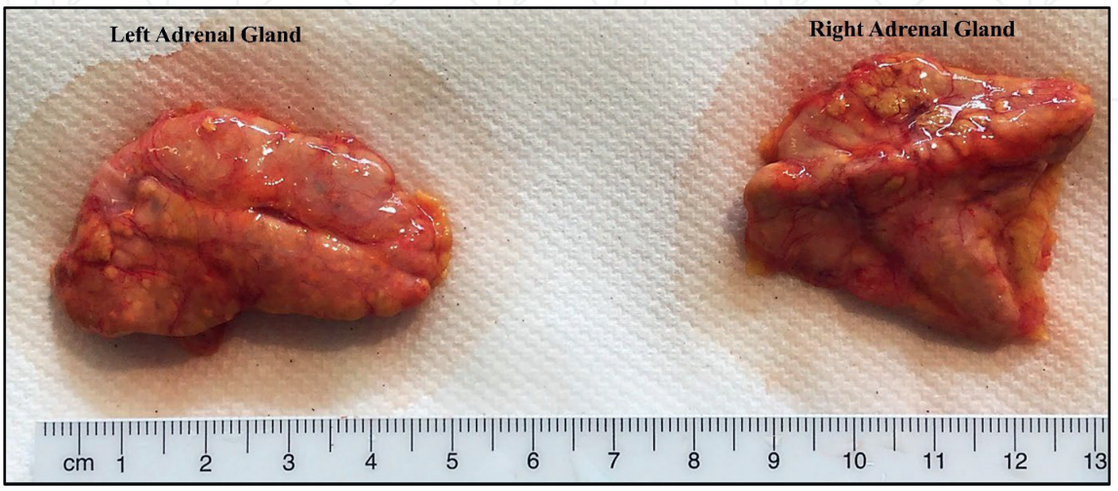

Figure 3.
Image of adrenal glands, anterior (left) and posterior (right) surface, with scale for measuring length. Image courtesy: Mikael Häggström, MD. Public Domain (CC0 1.0).

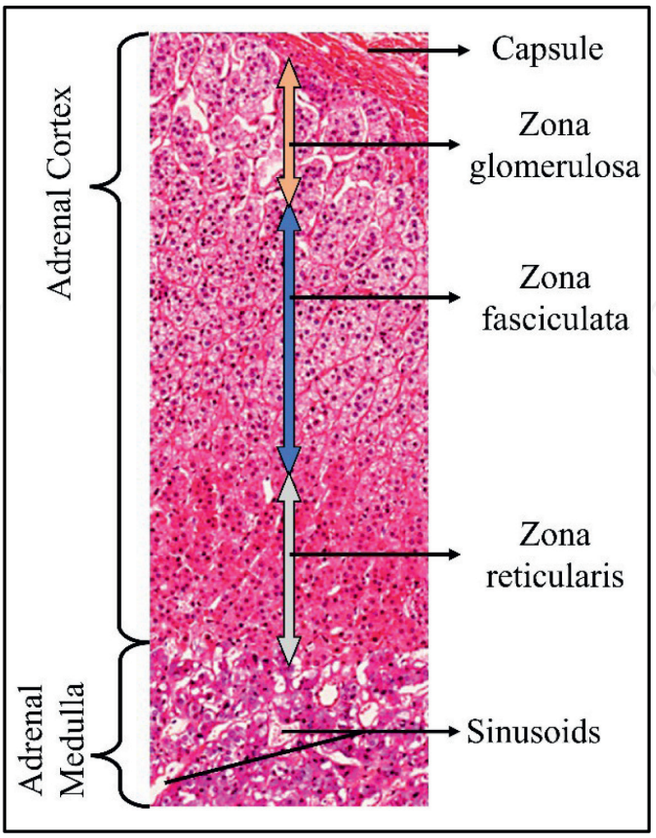

Figure 4.
Histological image of the adrenal showing different zones of the cortex and the medulla.

synthase, an enzyme, works primarily in this layer to produce the mineralocorticoid aldosterone, which is crucial for controlling blood pressure and maintaining salt concentration (**Table 1**) [5].

3.2 Zona fasciculata

The cells in this zone are organized in columns, or tape-like arrangements (hence the term 'fasciculata') radially orientated toward the medulla. It makes up around 80% of the cortex's volume, making it the thickest of the three layers. The fasciculata cells release glucocorticoids like cortisol, which regulates the metabolism of proteins, fats, and sugars (**Table 1**) [5].

3.3 Zona reticularis

The innermost layer of the adrenal cortex lies adjacent to the medulla. Here the tiny cells are arranged in the form of irregular cords and clusters (hence the term 'reticularis'). The capillaries and connective tissue can be found between these cords. These cells produce androgens in humans (**Table 1**) [5].

The central part of the gland, the medulla, contains chromaffin cells. These cells are the primary source of catecholamines, i.e., adrenaline and noradrenaline. The fight-or-flight response is characterized by the effects of the catecholamines, which include elevated heart rate and blood pressure, constriction of blood vessels in the skin and

Zones of the Adrenal gland	Hormones secreted	Hormonal effects	Regulatory controls
Zona Glomerulosa	Mineralocorticoids, Aldosterone	Increases renal reabsorption of sodium and water. It also increases urinary loss of potassium.	Mineralocorticoid secretion is stimulated by the activation of the renin-angiotensin system and is inhibited by hormones opposing that system.
Zona Fasciculata	Glucocorticoids, Cortisol	Glucocorticoids increase rates of glucose and glycogen formation by the liver.	Glucocorticoids secretion is stimulated by the Adrenocorticotropic hormone (ACTH)
Zona Reticularis	Androgens	Stimulates the development of pubic hair in boys and girls before puberty	Androgen secretion is stimulated by ACTH
Adrenal Medulla	Adrenaline And Noradrenaline	Increases cardiac activity, blood pressure, glycogen breakdown, and blood glucose levels.	Adrenaline and Noradrenaline secretion are stimulated by sympathetic preganglionic fibers during sympathetic activation.

Table 1.
Secretions of adrenal gland zones, their effects, and their regulatory controls.

gastrointestinal tract, dilatation of smooth muscle (bronchioles and capillaries), and increased metabolism (**Table 1**) [5].

4. Arterial supply, venous & lymphatic drainage

The blood supply rate per gram of tissue for the adrenal gland is one of the highest. This could only be achieved due to several arterial branches entering the gland, which are derived from three major branches (**Figure 1**) [8–10]:

a. Superior suprarenal artery - a branch of the inferior phrenic artery

b. Middle suprarenal artery - a direct branch of the abdominal aorta

c. Inferior suprarenal artery - a branch of the renal artery

On the contrary, each gland is drained by a single vein, namely

a. Right suprarenal vein which drains directly into the inferior vena cava

b. Left suprarenal vein which drains into the left renal or inferior phrenic vein.

The short cortical arteries form the subcapsular plexus branches. The plexus then provides an anastomosing network of capillary sinusoids that constitute the cortex's vascular system. These sinusoids infiltrate between the cords of zona fasciculata and then create the deep plexus in the zona reticularis, where they drain into minute venules that confluence with the principal vein of the medulla [7].

The medulla receives blood from two sources, the arterial medullary arterioles and the venous cortical sinusoidal capillaries, which have already fed the cortex and are high in adrenocorticosteroids. Long cortical arteries drop through the cortex from the subcapsular plexus and ramify into a dense network of dilated capillaries around the medullary secretory cells. The medullary capillaries then drain into the central medullary vein. Subsequently, the venous drainage of the cortex also supplies the medullary cells while crossing through the medulla on their way to the central medullary vein. The corticosteroids in the cortical venules are thought to significantly impact the medulla's ability to synthesize adrenaline [5, 7].

The lymph from the paired glands drains into lateral aortic nodes. The lymphatic vessels have been observed in the capsule, the connective tissue around the larger blood vessels, and the parenchyma of the adrenal medulla [11].

5. Nerve innervations

The adrenal is a neuroendocrine gland, i.e., the gland is regulated by both the pituitary hormones and nerve innervations. The cortical part of the gland is under the regulation of adrenocorticotrophic hormone released by the anterior lobe of the pituitary [5].

The adrenal medulla is considered a modified sympathetic ganglion as it is innervated by the myelinated pre-ganglionic sympathetic fibers coming from T5–T11 (splanchnic nerves) spinal levels and pours its secretion into the sinusoids, unlike other sympathetic ganglions [5].

6. Development

Either part of the adrenal gland is derived from two different embryological tissues. The adrenal cortex is derived from proliferated mesothelial cells around 5–6 weeks post-conception, while the medulla originates from the neural crest (**Figure 5**). The foetal adrenal cortex surrounds the growing adrenal medulla, and the entire gland is enclosed in a mesodermal layer that isolates it from the nearby developing gonad and kidney. The foetal adrenal cortex separates into two histologically distinct zones at about 9 weeks gestation: the definitive and foetal zones. Between the definitive and foetal zones, a third layer, the transitional zone, develops in the third trimester. The zona glomerulosa, the adrenal cortex's outer layer that generates mineralocorticoids, and the zona fasciculata, which produces glucocorticoids, are formed by 6 months of age from the definitive and transitional zones. The foetal cortex involutes throughout the first year of life, and the zona reticularis, which generates androgens, develops as the adrenal cortex's innermost layer. By 3 to 4 years, the zona reticularis differentiates into a separate layer (**Figure 6**) [6, 12].

It is interesting to note that medullary and cortical tissues combine to form a single organ in mammals, whereas they form into two separate organs in pre-vertebrates. The migration of medullary cells into the cortex, which starts in the seventh week of

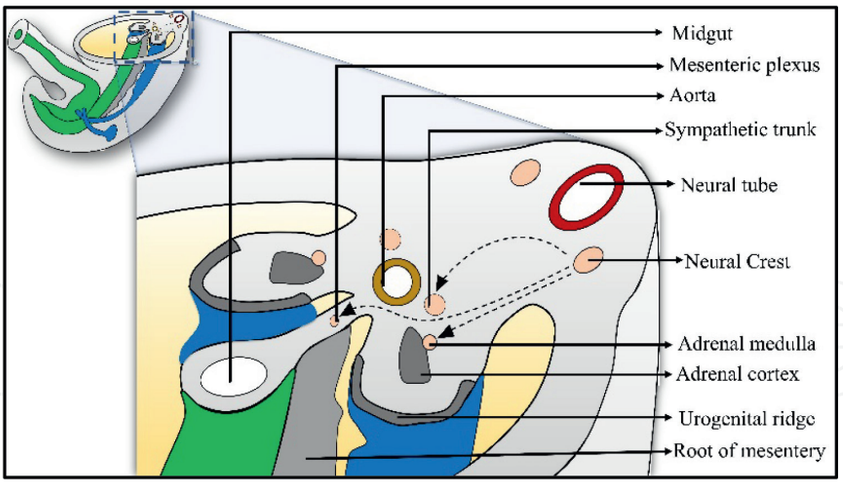

Figure 5.
Illustration of magnified view of a foetal section showing the developmental tissues of the adrenal cortex and medulla.

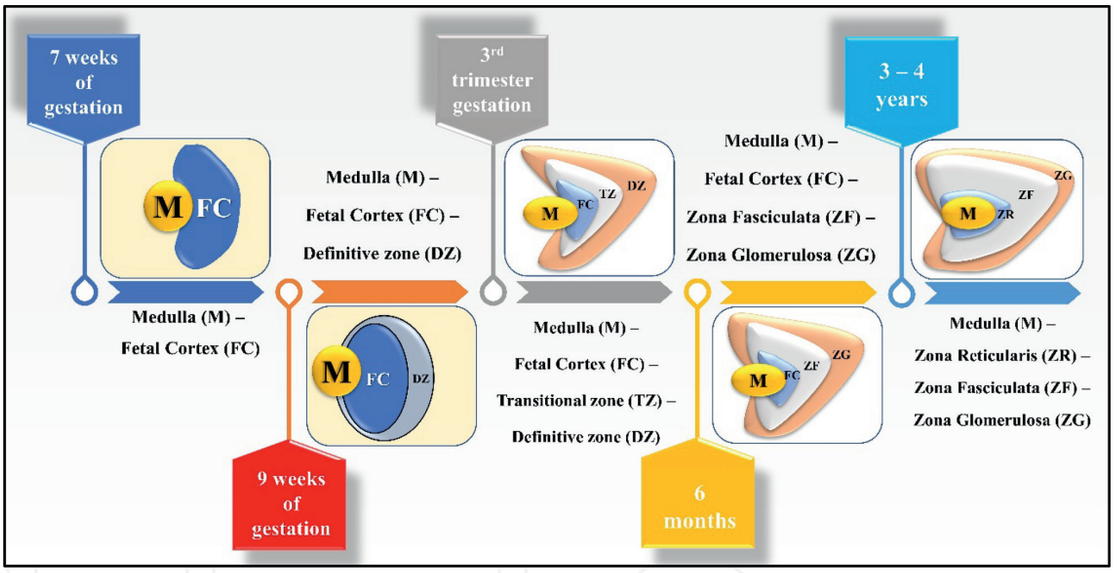

Figure 6.
Illustration of the timeline for the development of the zones of the adrenal cortex and the medulla in a foetus.

pregnancy, allows the primitive medullary and cortical cells to unite to form the adrenal gland. By the second trimester, the foetal adrenal cortex surrounds the medulla, and the entire gland is encased by a mesodermal layer, which isolates the adrenal glands from the nearby retroperitoneal structures [6, 13, 14].

Author details

Ravi Kant Narayan[1*], Ashutosh Kumar[2] and Manika Verma[3]

1 Dr.B.C. Roy Multi Speciality Medical Research Centre, IIT Kharagpur, India

2 All India Institute of Medical Sciences, Patna, India

3 Rajendra Institute of Medical Sciences, Ranchi, India

*Address all correspondence to: narayanintouch@gmail.com

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