

2 Surgical Anatomy

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2.1 Introduction

The small paired adrenal glands have a grand history. Eustachius published the first anatomical drawings of the adrenal glands in the mid-sixteenth century [17]. In 1586, Piccolomineus and Baunin named them the suprarenal glands. Nearly two-and-a-half centuries later, Cuvier described the anatomical division of each gland into the cortex and medulla. Addison would describe the classical symptoms of the condition still bearing his name in 1855, igniting intense interest in the gland [1]. The next year, Brown-Séquard proved the vital necessity of the glands by performing adrenalectomies in animals [3]. Harvey Cushing described hypercortisolism in 1912, and Conn detailed primary hyperaldosteronism in 1955 [4, 6]. The first successful resections for pheochromocytoma were performed in 1926 by Charles Mayo in America and Roux in Switzerland [5]. Because of the relative frequency of adrenal disorders, endocrine surgeons must have a sound knowledge regarding appropriate management [11]. A solid understanding of adrenal anatomy lays the groundwork for future chapters in this textbook.

2.2 Morphology

The paired retroperitoneal adrenal glands are found in the middle of the abdominal cavity, residing on the superior medial aspect of the upper pole of each kidney (Fig. 1). However, this location may vary depending on the depth of adipose tissue. By means of pararenal fat and perirenal fascia, the adrenals contact the superior portion of the abdominal wall. These structures separate the adrenals from the pleural reflection, ribs, and the subcostal, sacrospinalis, and latissimus dorsi muscles [2]. Posteriorly, the glands lie near the diaphragmatic crus and arcuate ligament [10]. Laterally, the right adrenal resides in front of the 12th rib and the left gland is in front of the 11th and 12th ribs [2]. Each adrenal gland weighs approximately

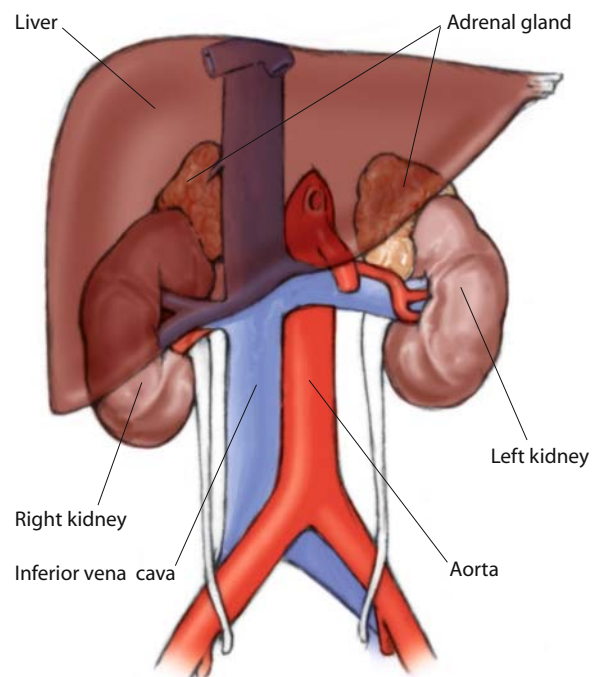


Fig. 1. In situ location of the adrenal glands. (After [10, p. 152])

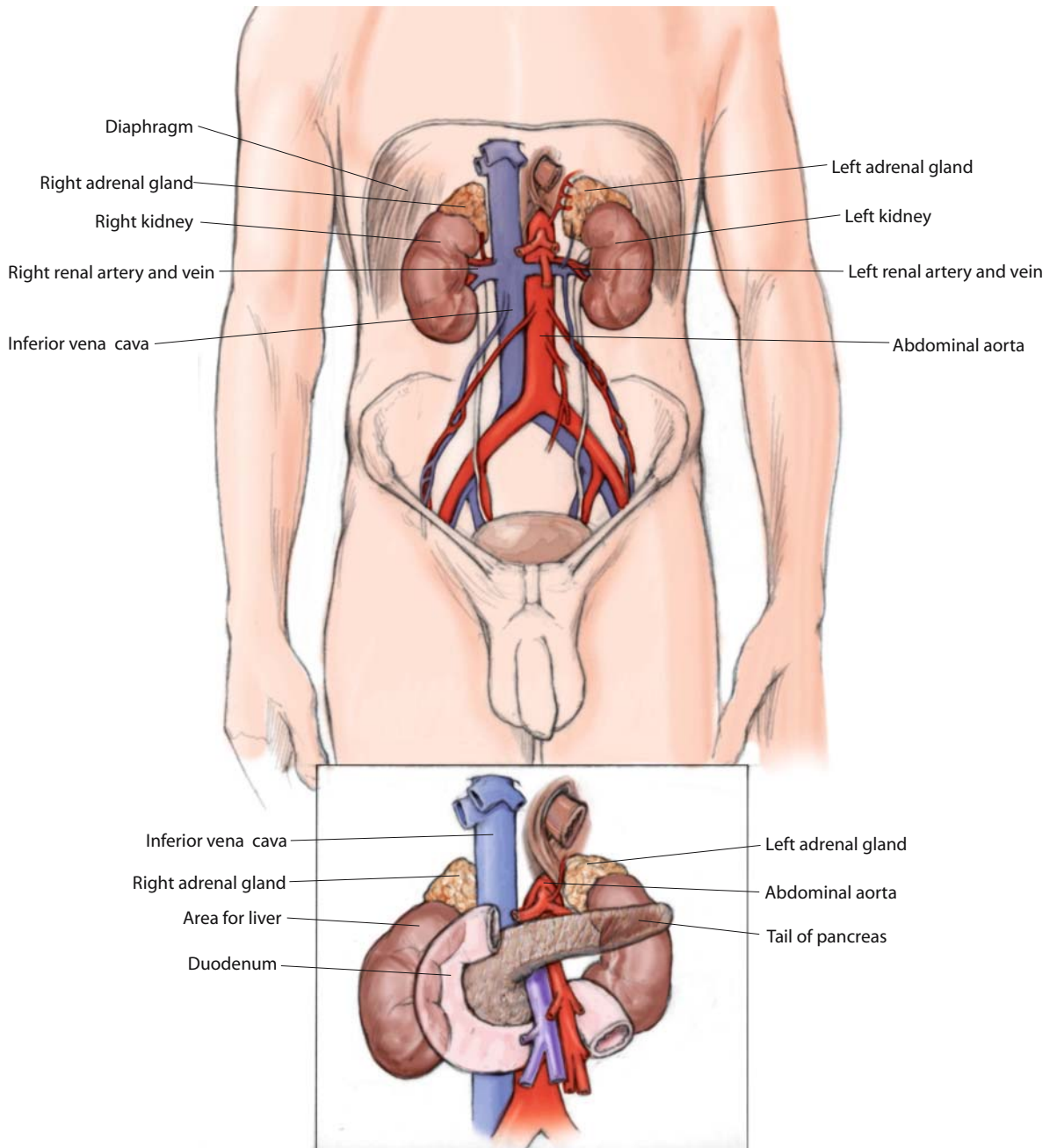


Fig. 2. Normal anatomical relationships of the adrenal glands. (After [12, p. 274])

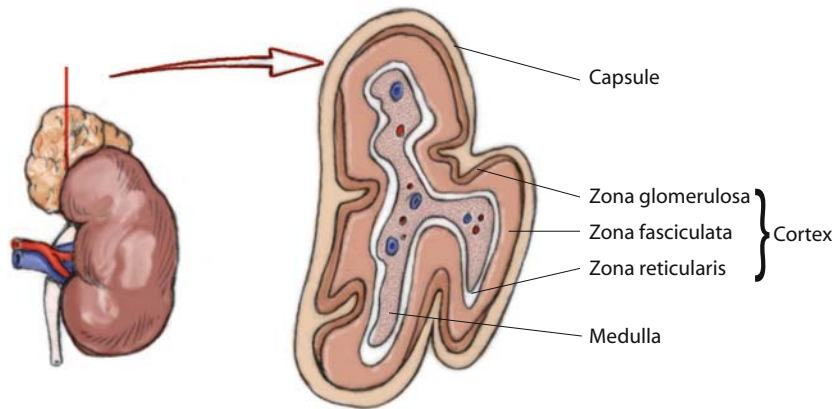


Fig. 3. Microscopic anatomy of the adrenal gland. (After [9, p. 1904])

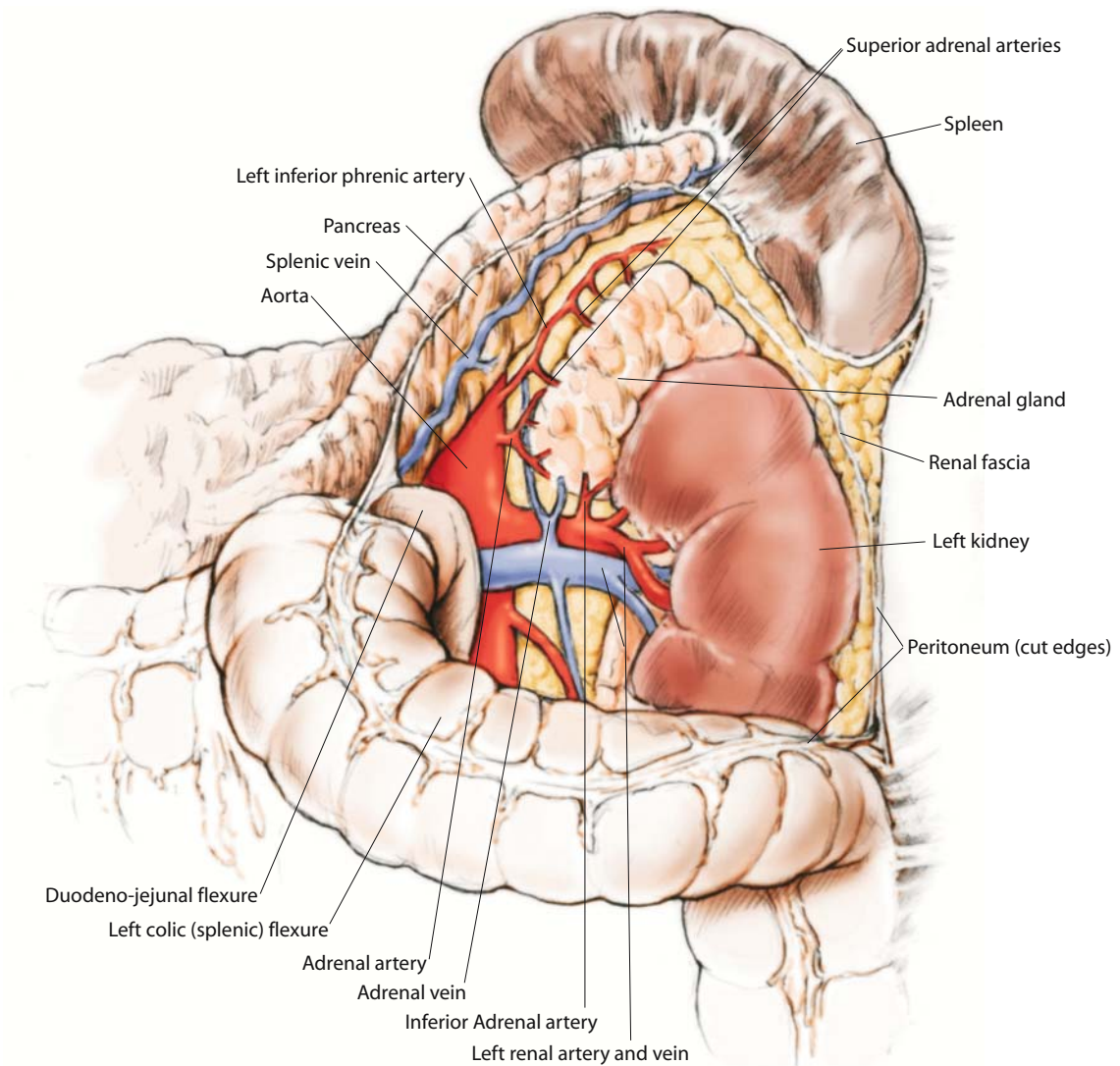


Fig. 4. Anatomical relationships of the left adrenal gland during an open surgical approach. (After [14a, plate 333])

3–6 g and measures roughly 5×2.5×0.5 cm [10]. Adrenal weight may increase by nearly 50% during periods of stress and pregnancy and pathologic glands may reach 700 g [12, 16].

The pyramid-shaped right adrenal gland (Fig. 2), sometimes called the “witch’s hat,” lies posterior and lateral to the inferior vena cava; it often touches the right diaphragmatic crus and bare area of the liver. The semilunar left adrenal gland (Fig. 2) is larger and flatter. It is located just lateral to the aorta, immediately posterior to the superior border of the pancreas, and medial to the superior pole of the kidney [8]. A thick, collagenous capsule sends deep trabeculae into the cortex and contains an arterial plexus supplying branches to the adrenal gland [9].

The adrenal cortex is a characteristic bright chrome yellow with a finely granular surface and firm consistency, allowing it to be readily differentiated from surrounding adipose tissue [2, 5]. The cortex is divided into three zones (Fig. 3) [9]. The *zona glomerulosa* secretes the mineralocorticoid aldosterone, which regulates salt and water homeostasis. The *zona fasciculata* secretes the glucocorticoid cortisol, which regulates carbohydrate metabolism. It comprises 75% of the cortical region [15]. The *zona reticularis* secretes sex steroids (progesterone, estrogen precursors, and androgens). The adrenal cortex is derived from the urogenital portion of the coelomic mesoderm [10]. The central medulla is dark red or pearly gray, depending on the blood content, and is rather friable. It secretes catecholamines which modulate the fight-or-flight response to stress [2, 5, 9, 14]. It originates from neural crest ectoderm and accounts for approximately one-tenth of the gland [9, 10]. It is completely enclosed by the adrenal cortex, except at the hilum [9].

True accessory adrenal glands contain both cortical and medullary tissue – these are very rare. However, nodules of adrenal cortical tissue are not uncommonly located in periadrenal fat, and ectopic cortical tissue may be found in the spleen, below the kidneys, or with the testes or ovaries [10]. Three percent of the general population has macroscopic adrenal nodules [12].

2.3 Relationship of the Adrenal Glands to the Kidneys

The adrenal glands are enclosed with their corresponding kidney via Gerota’s (perirenal) fascia and are embedded in perirenal fat (Fig. 4) [10]. A transverse lamella separates the adrenals from the kidneys, enabling separate removal of either organ. The glands are

attached to the diaphragm via ventral and dorsal layers of renal fascia, allowing them to move with the diaphragm, occasionally causing difficult hemostasis [2].

2.4 Blood Supply, Innervation, and Lymphatics

2.4.1 Arterial

The arterial supply of the adrenal gland is contributed by 12 small arteries from the aorta, inferior phrenic, renal and intercostal arteries. These tributaries branch to form a subcapsular arteriolar plexus from which capillaries enter the cortex in a radiating, spoke-like fashion (Fig. 5) [7, 10]. The adrenal arteries are also referred to as suprarenal arteries in many textbooks. The *superior adrenal artery* is a branch of the inferior phrenic artery and is located along the superior medial margin of the gland. The *middle adrenal artery* originates from the abdominal aorta. The *inferior adrenal artery* arises from the renal artery and is found along the inferior-medial margin of the gland [8, 16]. These arteries anastomose over the surface of the gland, and small unbranched arteries descend through the capsule. The right adrenal is mainly supplied by the superior and inferior adrenal arteries, whereas the left adrenal is mostly supplied via the middle and inferior adrenal arteries. Arterial and venous capillaries within the gland integrate the function of the cortex and medulla. Cortisol-rich effluent flows from the cortex to the medulla, where it stimulates the synthesis and activity of phenylethanolamine-*N*-methyl transferase, leading to the conversion of norepinephrine to epinephrine. Extra-adrenal chromaffin tissues lack this mechanism, thereby secreting mostly norepinephrine [16].

2.4.2 Venous

In contrast to the intricate arterial network, there is a single central vein exiting at the hilum of the adrenal glands (Fig. 5) [18]. Blood percolates within the gland from the medulla to the central medullary system, forming the large *adrenal vein*. Many accessory adrenal veins follow the course of the arteries and empty into the inferior phrenic vein, renal vein, or a venous arc in connection with the azygous system and posterior gastric veins. These collaterals form a caval or portal shunt and can enlarge with significant tumors [2].

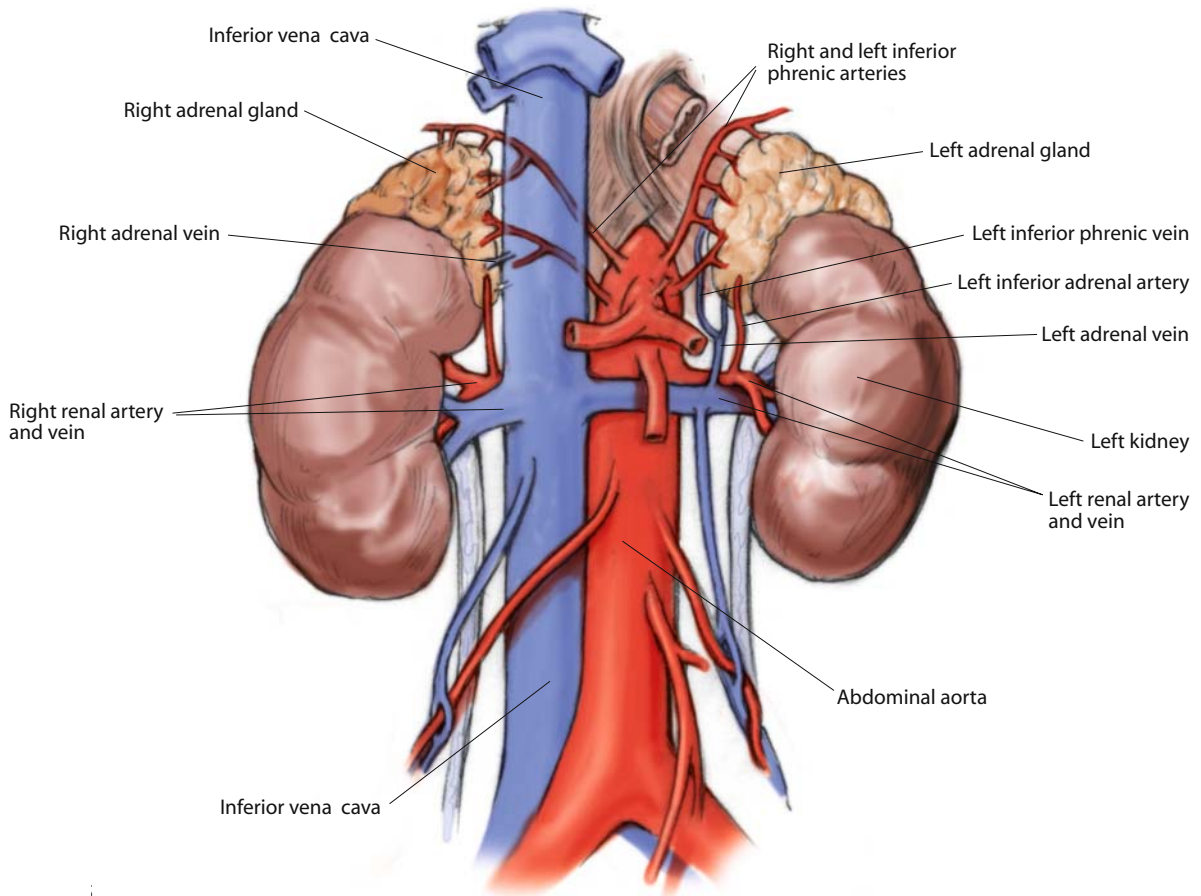


Fig. 5. Arterial supply and venous drainage of the adrenal glands. (After [12, p. 275])

2.4.3 Innervation

Innervation of the adrenal glands is via visceral afferent fibers arising from the *celiac*, *aorticorenal*, and *renal ganglia*. These fibers connect with the posterior *vagus nerve*, *phrenic nerve*, and greater and lesser *splanchnic nerves* (Fig. 6). They provide sensory or indirect vasomotor innervation as they pass through the cortex. They terminate in the medulla as preganglionic sympathetic fibers. It should be remembered that the adrenal medulla is a postsynaptic sympathetic nerve, belonging to the nervous system as such [2].

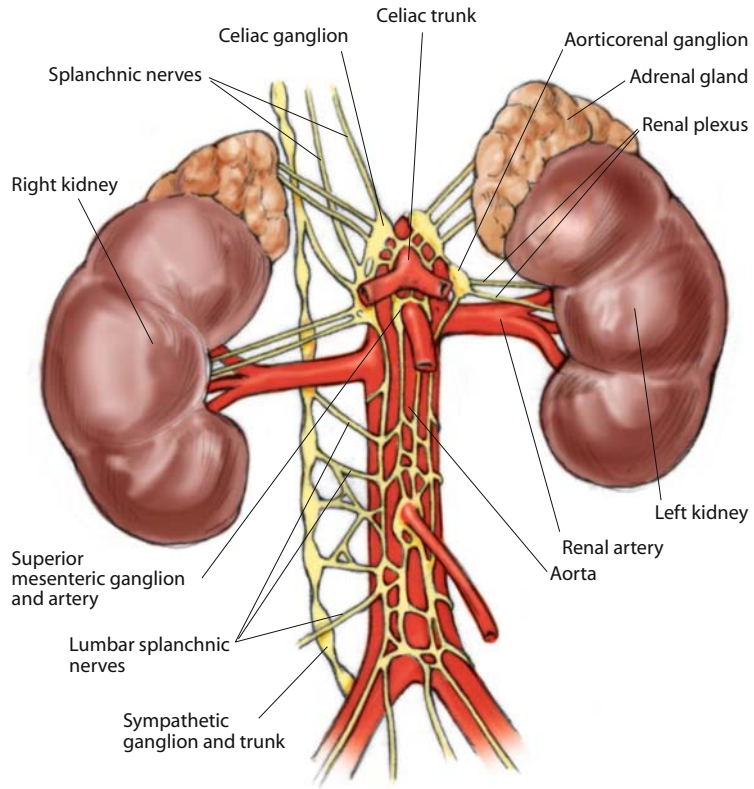
2.4.4 Lymphatic

The lymphatic drainage of the adrenal glands arises from a plexus deep in the adrenal capsule and a plexus in the adrenal medulla, emptying into the renal lymph nodes (Fig. 7). They follow the large vessels in three main pathways. On the right, a pathway terminates in

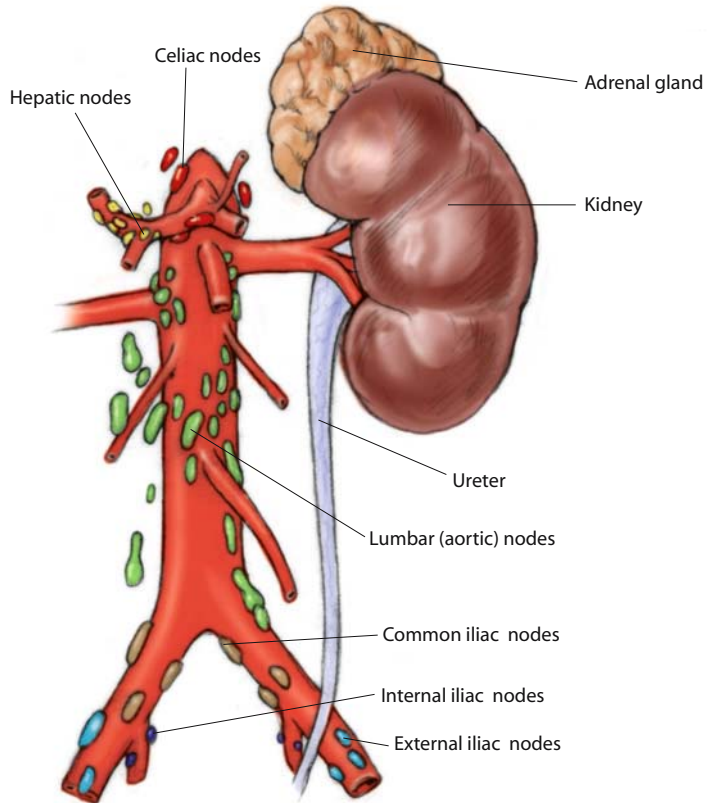
the right lateral *lumbar (aortic) nodes* in front of the right diaphragmatic crus, proximal to the celiac trunk. A second pathway ends in the right lateral aortic nodes proximal to the junction between the left renal vein and vena cava. A third pathway ends in the *thoracic duct* or in the *posterior mediastinal nodes* after piercing the crura of the diaphragm. This is an important route for metastatic spread of adrenal cortical tumors. Of note, lymphatic vessels drain only the cortex, not the medulla [2].

2.5 Left Adrenal Gland Relationships

The left adrenal gland is related to the left hemidiaphragm, tail of the pancreas, splenic artery, and left renal vein (Fig. 8A, B). The visible relationships of the left adrenal gland during a laparoscopic approach contrast with those during an open surgical approach (Figs. 4, 9). This gland is crescentic, being convex medially and concave laterally. The superior border is



▲
Fig. 6. Innervation of the adrenal glands. (After [1a, p. 157])



▶
Fig. 7. Lymphatics of the adrenal glands. (After [14, p. 290])

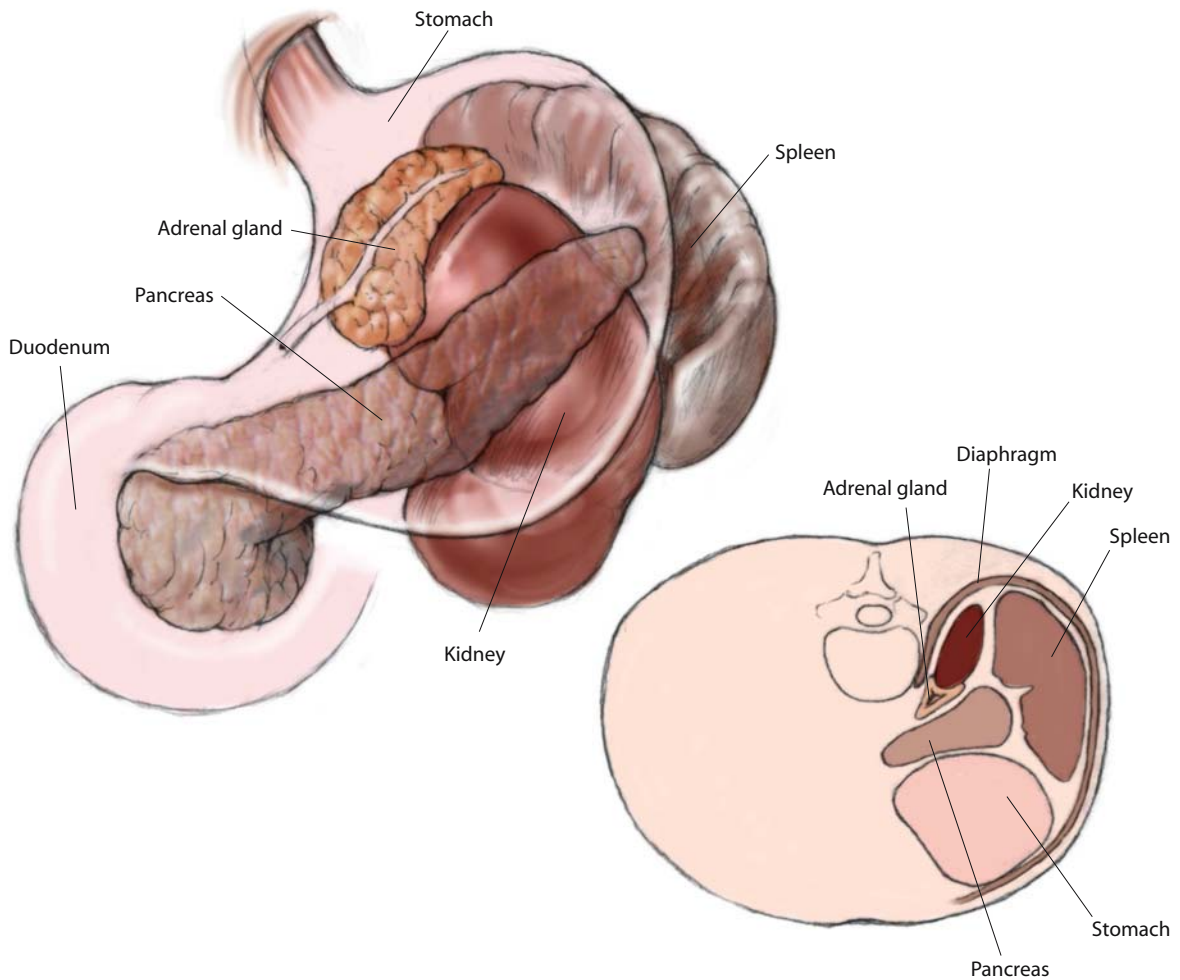


Fig. 8. Anterior anatomical relationships of the left adrenal gland. Posterior anatomical relationships of the left adrenal gland. (After [9, p. 1902])

sharp and the inferior border is rounded. In contrast to the right adrenal gland, the superior half of the *anterior surface* of the left adrenal gland is covered anteriorly via peritoneum of the lesser sac (Fig. 10) [18]. This separates the gland from the cardia of the stomach and the posterior pole of the spleen. Inferiorly, where the gland contacts the pancreas and splenic artery, there is no peritoneum [9, 18]. The left adrenal vein emerges at the hilum of the gland. A ridge divides the *posterior surface* into a lateral area adjoining the kidney and a smaller medial region contacting the left crus of the diaphragm. The *medial border* is convex and related to the inferomedial left celiac ganglion and to the left inferior phrenic and left gastric arteries, which ascend on the left diaphragmatic crus [9].

The ventral aspect of the left adrenal gland is attached to the dorsal viscera of the stomach and to the

medial border of the spleen and the body of the pancreas. Both the splenic vein and the splenic artery are inferior to the left adrenal gland. The avascular segment of the gastrocolic ligament is commonly divided during surgery on the left adrenal gland. The transverse mesocolon attaches along the inferior border of the pancreas; it is retracted inferiorly and medially for operative exposure [2].

The left adrenal gland is located in front of the origin of the celiac trunk but it is separated from the aorta by a space of several millimeters [2]. The left adrenal vein is approximately 2–3 cm long, passing inferiorly from the lower pole of the gland, receiving the inferior phrenic vein, then taking an oblique downward course to enter the left renal vein (Fig. 5) [2, 8]. Occasionally, the vein empties into the left inferior phrenic vein (which then enters into the left renal vein)

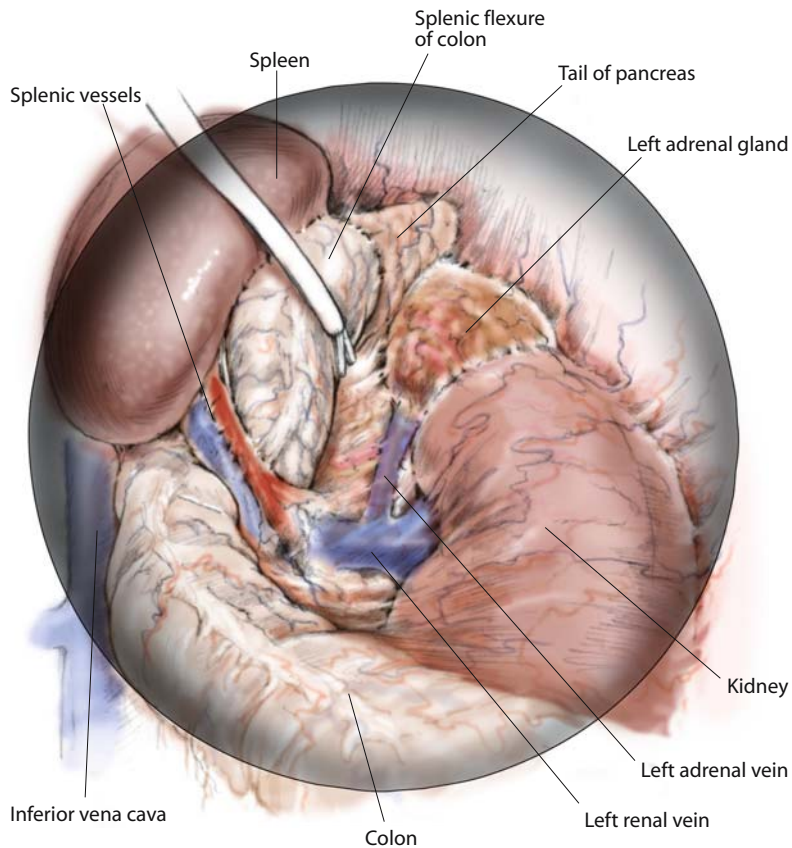


Fig. 9. Anatomical relationships of the left adrenal gland during a laparoscopic approach. (After [18, pp. 172, 173])

or crosses over the aorta to enter directly into the inferior vena cava [10]. The length of the left adrenal vein allows for ready vascular control during left adrenalectomy [2].

2.6 Right Adrenal Gland Relationships

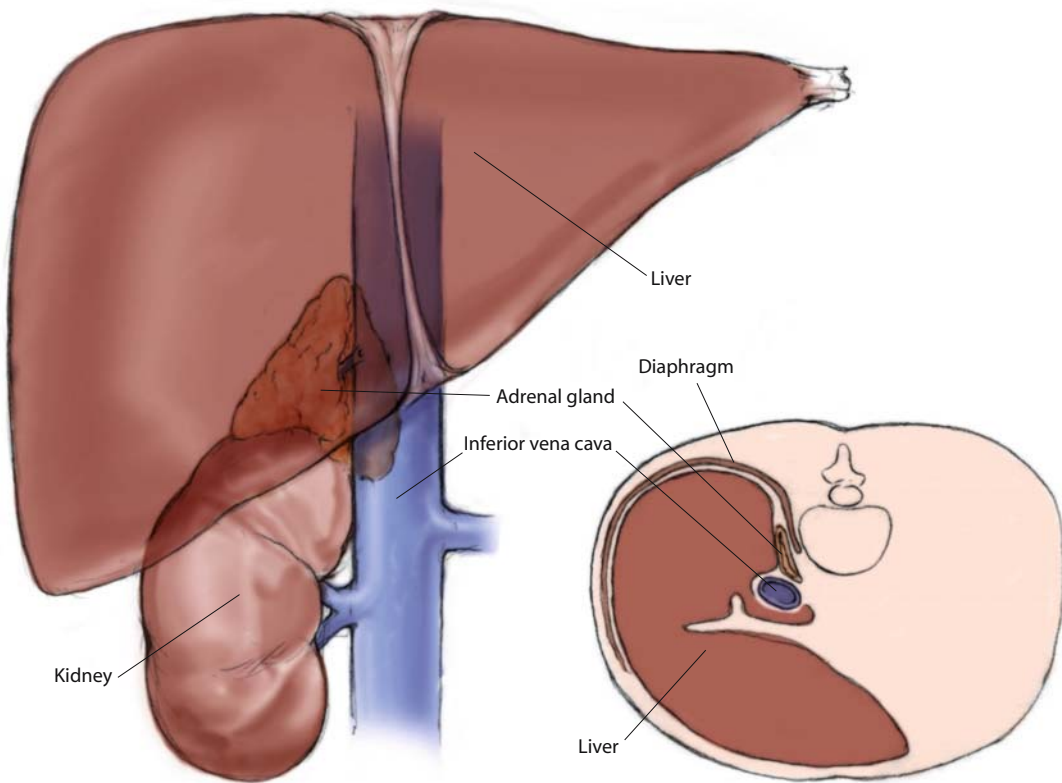
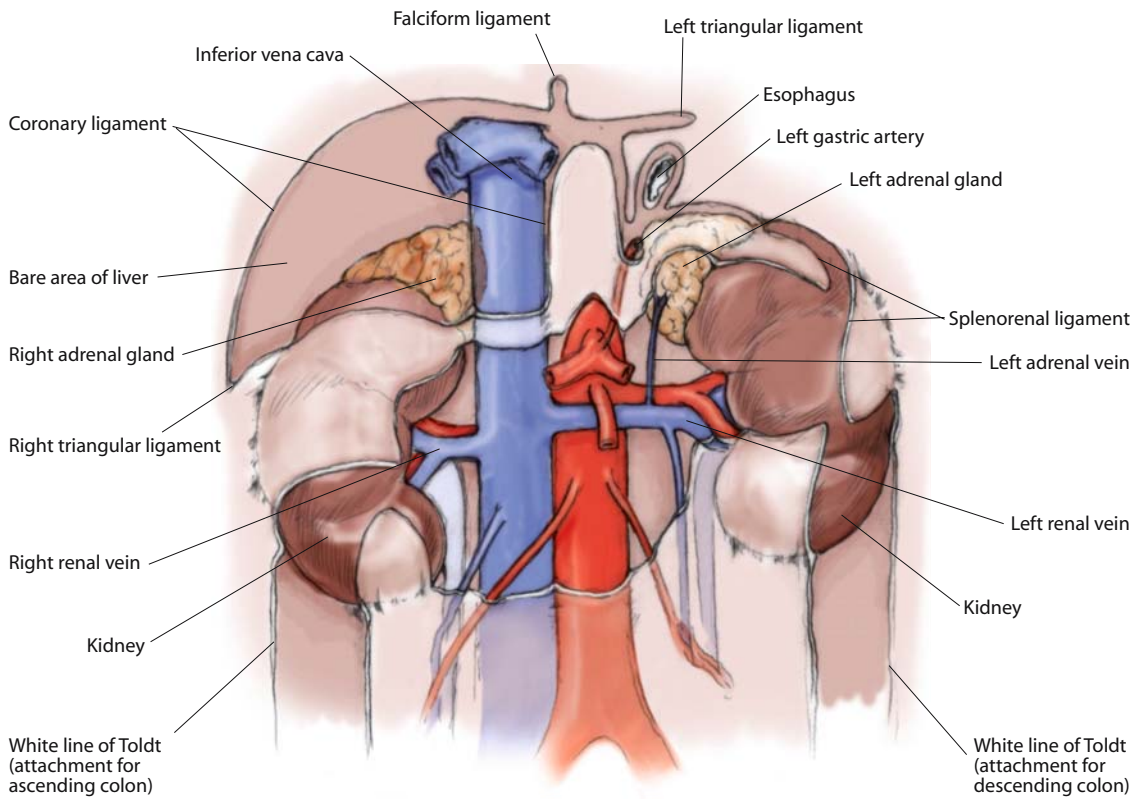
The right adrenal gland is posterior to the inferior vena cava and right hepatic lobe and anterior to the diaphragm and superior pole of the right kidney (Fig. 11A, B) [9]. The anatomical relationships of the right adrenal gland appear quite different in a laparoscopic versus an open surgical approach (Figs. 12, 13). The *anterior surface*, which faces slightly laterally, has a narrow vertical medial area devoid of peritoneum which is posterior to the inferior vena cava. The anterior surface is nearly totally covered by the bare area of the liver (Fig. 10) [10, 18]. The upper portion of the lateral triangular area is also devoid of peritoneum and contacts the inferomedial angle of the bare area of the liver. The inferior portion of the lateral part may be

covered by peritoneum reflected from the inferior layer of the coronary ligament; the duodenum may overlap this region as well. Below the apex, near the anterior border of the gland, is the short hilum where the right adrenal vein emerges to join the inferior vena cava [9].

The ventral-lateral region of the right adrenal gland is overlapped by the peritoneum between the liver, kidney, and hepatic flexure of the colon [18]. The ventral-medial area is behind the inferior vena cava, separating the gland from the epiploic foramen anteriorly and the third portion of the duodenum and pancreatic head posteriorly. The body of the pancreas separates the adrenal gland from the lesser sac (omental

Fig. 10 (above). Peritoneal attachments of the adrenal glands. ► (After [18, p. 169])

Fig. 11 (below). A Anterior anatomical relationships of the right adrenal gland. B Posterior anatomical relationships of the right adrenal gland. (After [9, p. 1902])



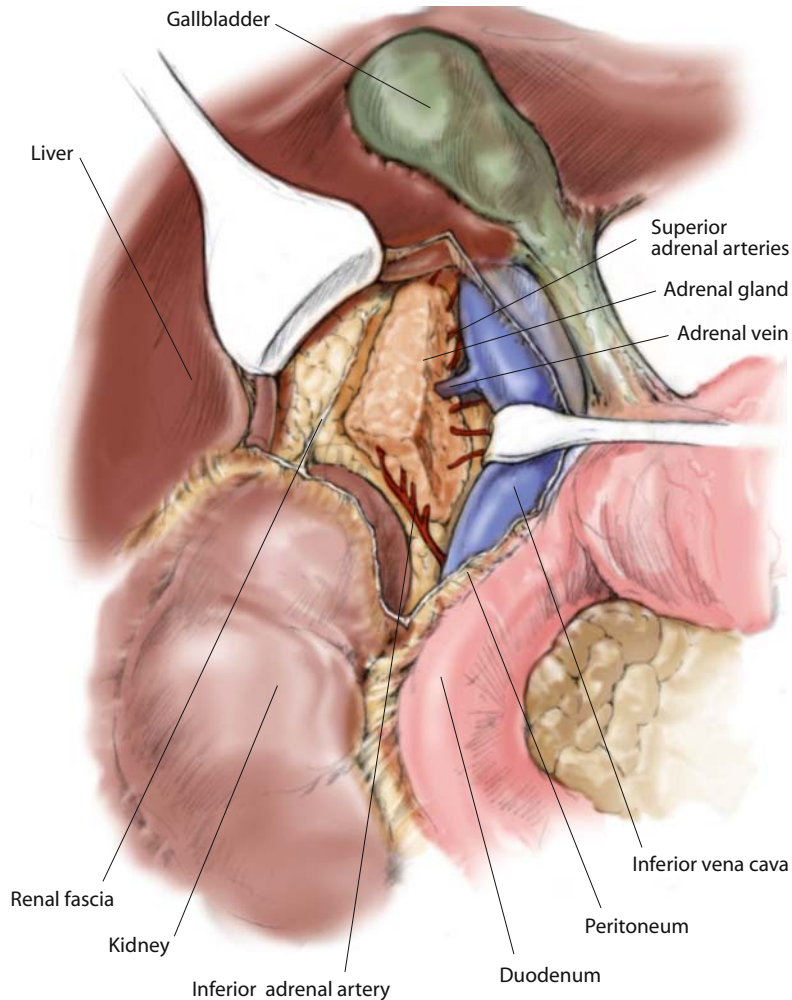


Fig. 12. Anatomical relationships of the right adrenal gland during an open surgical approach. (After [14a, plate 333])

bursa) and stomach [2]. The *posterior surface* is divided into upper and lower areas via a curved transverse ridge: its upper area, slightly convex, rests on the diaphragm, while the lower concave area contacts the superior pole and adjacent anterior surface of the right kidney. The thin *medial border* is related to the right celiac ganglion and the right inferior phrenic artery [9]. The medial border contacts, and may extend posteriorly towards, the inferior vena cava and is sometimes tucked behind it [10, 18]. If the inferior layer of the right coronary ligament is high, the right adrenal gland may partially reside in the right paracolic gutter (Morrison's pouch) where it contacts the peritoneum [18].

The right adrenal vein exits the hilum on the antero-medial surface of the gland (Fig. 5) [18]. It emerges for

a mere 1 cm and takes a short, almost transverse route, at a 45° angle, to empty into the posterior segment of the inferior vena cava [8, 18]. The right adrenal vein cannot be exposed until the adrenal gland is mobilized [18]. The origin of this vein may be obscured by an enlarged gland. This is extremely important since accidental nicking of the inferior vena cava during adrenalectomy may cause fatal hemorrhage [2, 13]. Therefore, expert care is necessary when dissecting the right adrenal vein [12]. The right inferior phrenic vein is usually very small and is a direct tributary of the inferior vena cava [18]. Additional smaller veins are found in 5–10% of right adrenal glands. Rarely, aberrant veins may drain into the right hepatic vein or right renal vein. Knowledge of such anomalies is essential to avoid accidental ligation of the renal vein [12].

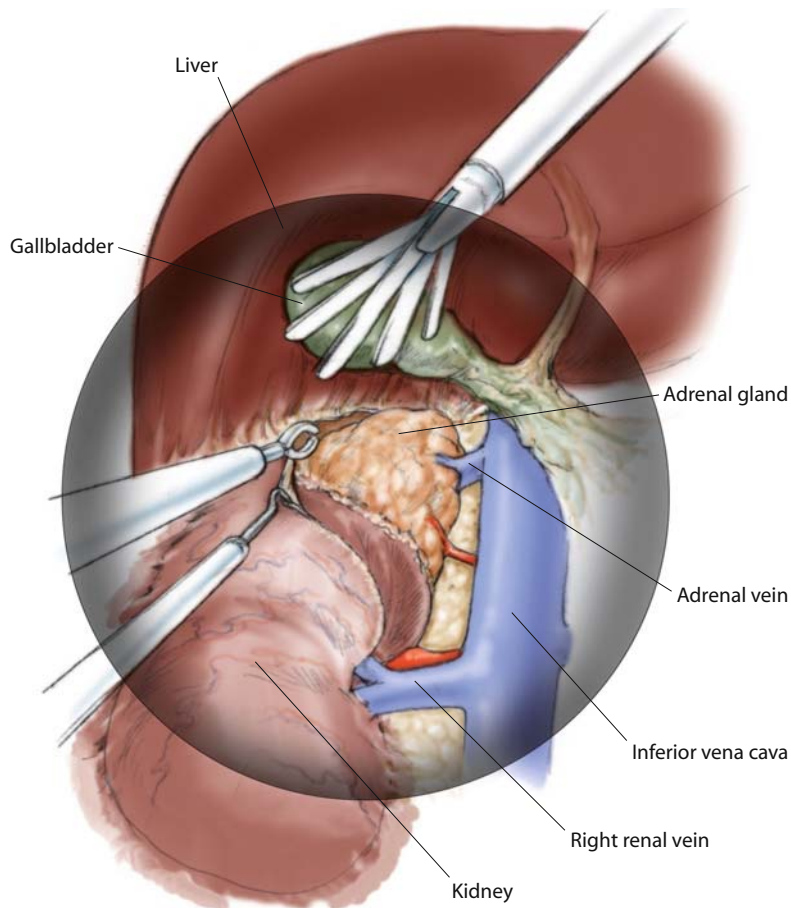


Fig. 13. Anatomical relationships of the right adrenal gland during a laparoscopic approach. (After [18, pp. 170, 171])

2.7 Summary

The adrenal gland represents two endocrine systems – the cortex and the medulla. Although these regions are small in comparison to many organs, they can lead to significant pathology from either primary or metastatic hyperfunctioning neoplasia or hyperplasia. The details of various adrenal disorders will be discussed in subsequent chapters. From the miraculous work of renowned surgeons like Mayo, Thorton and Young, adrenalectomy became a safe and effective therapy for adrenal disorders [12]. Because adrenal surgery is often the primary treatment modality for a multitude of adrenal conditions, a strong working knowledge of adrenal anatomy is essential.

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