

What the radiologist needs to know: the role of preoperative computed tomography in selection of operative approach for adrenalectomy and review of operative techniques

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Abstract

Adrenalectomy is the standard of care for management of many adrenal tumor types and, in the United States alone, approximately 6000 adrenal surgeries are performed annually. Two general approaches to adrenalectomy have been described; (1) the open approach, in which a diseased adrenal is removed through a large (10–20 cm) abdominal wall incision, and (2) the minimally invasive approach, in which laparoscopy is used to excise the gland through incisions generally no longer than 1–2 cm. Given these disparate technique options, clear preoperative characterization of those specific disease features that inform selection of adrenalectomy approach is critically important to the surgeon. Because most of these features are directly assessed via preoperative abdominal imaging, in particular computed tomography (CT) scanning, a clear mutual understanding among surgeons and radiologists of those adrenal tumor features impacting operative approach selection is vital for planning adrenal surgery. In this context, we review the preoperative CT imaging features that specifically inform adrenalectomy approach selection, provide illustrative examples from our institution's imaging and surgical archives, and provide a stepwise guide to both the open and laparoscopic adrenalectomy approaches.

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Adrenal tumors can develop from the peripheral layer (cortex) or from the central medullary tissue of the adrenal gland. Under normal circumstances, the adrenal glands regulate body function through synthesis and secretion of hormones, including hormones controlling blood pressure, metabolism, and the stress-response [1]. Because they represent expansions of adrenal tissue, adrenal tumors can cause significant morbidity by over producing one or more adrenal hormones, depending on the adrenal subdomain from which they originate. Furthermore, a minority of adrenal tumors will represent adrenocortical carcinoma (ACC), which generally carries a very poor prognosis. Optimal treatment for functional adrenal tumors, and for adrenal tumors suspicious for malignancy, requires prompt diagnosis, generally followed by adrenalectomy [2].

A laparoscopic approach to adrenal tumor excision is the preferred surgical method, due to associated shorter recovery time and lower risk of operative complications, relative to the open approach [3, 4]. Laparoscopic adrenalectomy involves the transabdominal insertion of a small video chip camera, and other surgical instruments, into the peritoneal space through specially designed ports, allowing the surgeon to resect an adrenal tumor through 5–12 mm incisions. Relative to an open approach, this technique provides lower perioperative morbidity and mortality, shorter hospitalization time,

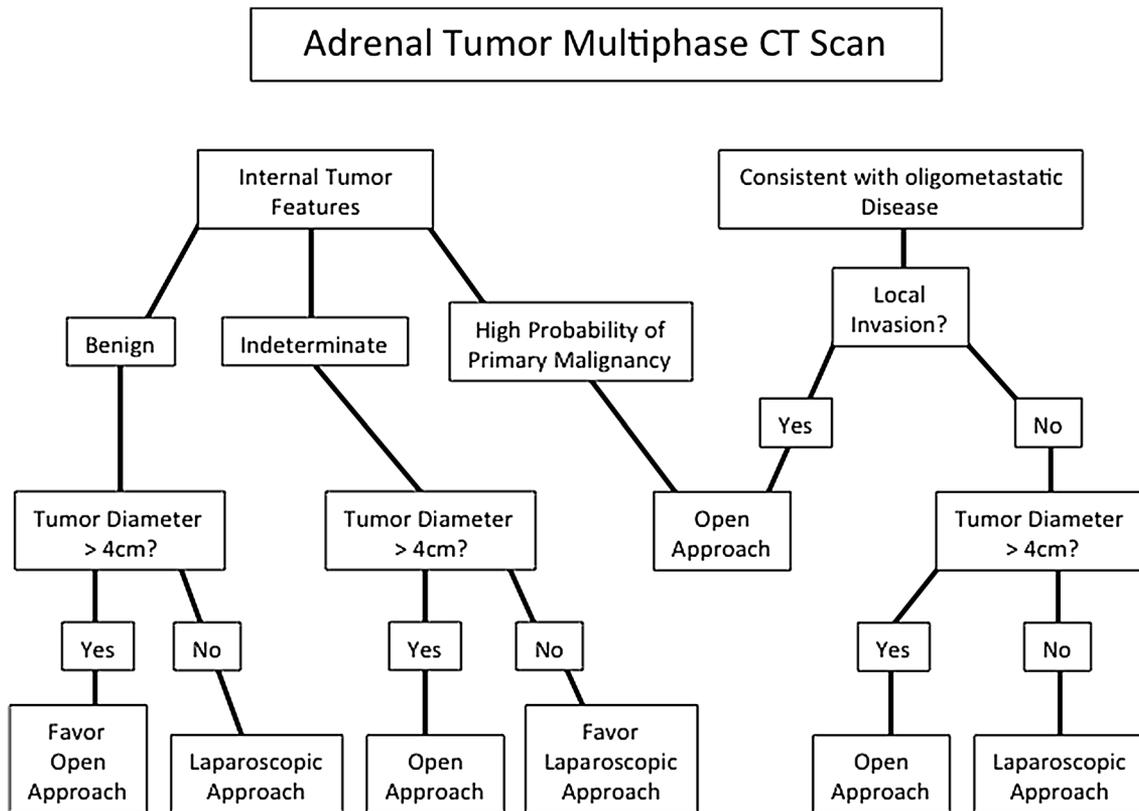


Fig. 1. Flow schematic for operative approach decision making on the basis of multi-phase CT scan findings.

better cosmetic results, reduced postoperative narcotic analgesic requirements, and improvement in the postoperative interval to normal dietary intake [5]. However, controversy persists as to the appropriateness of the laparoscopic approach under some circumstances, particularly for large adrenal tumors and for suspected ACC [6–9]. For ACC in particular, open adrenalectomy has been associated with improved oncologic outcomes, secondary to lower rates of intraoperative tumor capsule violation and to lower risk of tumor margin positivity, despite the more significant short-term morbidity inherent to this invasive technique (relative to its laparoscopic counterpart) [10–14]. Thus, selection of an optimal adrenalectomy approach depends on the accurate appraisal of possible underlying diagnoses. Because such appraisal is dependent on the radiologist's assessment of associated imaging, a mutual understanding between surgeons and radiologists of those specific imaging findings that impact operative approach selection is very important. In our own experience, such understanding is not universal and we therefore review here the critical CT imaging features that drive selection of adrenalectomy approach (Fig. 1). Although multiple different imaging modalities have been employed for assessment of adrenal tumors, including MRI, ultrasound and nuclear imaging, we have found multi-phase (so called adrenal protocol) CT scanning to be most informative for purposes of

operative planning. In addition to clearly defined criteria for identification of benign disease, multi-phase CT scanning provides improved anatomic resolution, in particular for associated vascularity/vascular supply, relative to other adrenal imaging options [15–17]. This anatomic resolution is critically important when planning adrenal surgery.

CT characteristics that impact operative approach selection for adrenalectomy

Adrenal CT scanning provides information that determines the potential for successful laparoscopic adrenal resection, including lesion size, characteristics of surrounding anatomy, and tumor features suggestive of malignancy (including degree of tissue heterogeneity, lesion vascularity, presence of calcifications, necrosis, and local invasion) (Fig. 1).

It is important to note that percutaneous image-guided needle biopsy plays, at most, a very limited role in the preoperative diagnosis of adrenal tumors, thus increasing the importance of imaging during adrenal tumor work-up. For ACC, preoperative biopsy is generally not helpful, as this technique cannot reliably distinguish between benign and malignant cortical tumors and is thus of limited (or no) diagnostic value [18]. In addition, needle biopsy-mediated disruption of the tumor

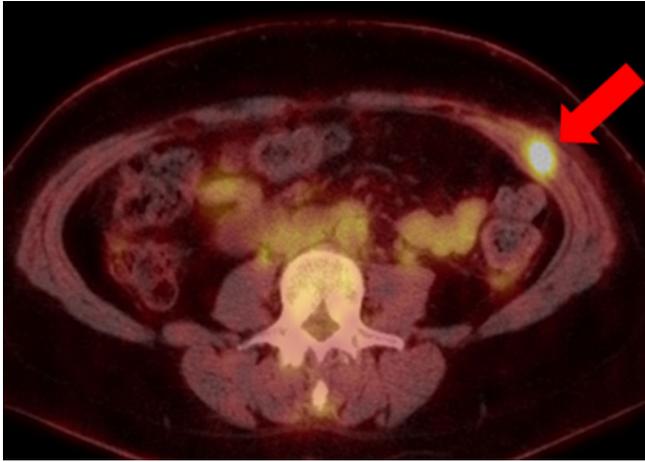


Fig. 2. Axial PET CT image in a 45 year-old woman who previously underwent image-guided needle biopsy of a left adrenal tumor which, following open resection, proved to be an ACC. An FDG-avid abdominal wall soft tissue mass is shown (red arrow), representing metastatic seeding of the biopsy needle track.

capsule in cases of ACC might significantly worsen prognosis by facilitating cancer cell access to the peritoneal space, thus resulting in peritoneal carcinomatosis, or seeding of the biopsy needle tract (Fig. 2). Nonetheless, an inappropriate recommendation to proceed with image-guided needle biopsy is relatively common when adrenal tumor imaging findings are not clearly benign. Image-guided adrenal biopsy has also been associated with complication risks exceeding 10%, including significant adrenal gland hemorrhage and, in cases of pheochromocytoma, hypertensive crisis [19, 20]. Finally, adrenal biopsy plays no role in assessing adrenal tumor hormonal activity, which is readily quantified through blood, saliva, and/or urine biochemical testing. Scenarios in which image-guided biopsy may provide useful information are limited to cases of suspected metastasis to an adrenal gland, for which biopsy material can facilitate identification of the originating site for an otherwise unknown primary tumor, and to cases of adrenal infection, for which the causative organism is unknown [21, 22].

Adrenal tumor size

A definitive adrenal tumor size above which an open surgical approach is indicated remains controversial. Most commonly, a tumor diameter of > 4–6 cm has been accepted as a relative contraindication to laparoscopic adrenalectomy (Fig. 1) [23]. This threshold is based on three concerns specifically related to the laparoscopic approach for large tumors: (1) potential for decreased safety, (2) mechanical constraints inherent to laparoscopy, and (3) increased risk of poor oncologic outcome in cases of malignancy. With regard to the

safety of laparoscopic surgery for large adrenal tumors, published data remain equivocal. Several investigators have reported that adrenal tumors ≥ 5 cm can be removed laparoscopically, although blood loss and complication rates are higher, and associated hospital stays longer, relative to smaller laparoscopically resected adrenal tumors [24–26]. Feo and colleagues reported that experienced surgeons could resect adrenal tumors ≥ 5 cm laparoscopically, with surgical outcomes similar to those associated with smaller tumors, although tumors ≥ 8 cm were associated with longer operative times [9]. A study by Natkaniec et al. examined a series of 441 patients undergoing laparoscopic adrenalectomy, determining that laparoscopic surgery for tumors ≥ 6 cm was more difficult than for smaller tumors and identifying a linear relationship correlating tumor size, procedure duration and intraoperative blood loss [14]. Finally, large tumors successfully resected laparoscopically will not be readily removed from the peritoneal space through the very small incisions afforded by laparoscopy without either significantly extending the length of the exit port incision (thus potentially confounding the advantages associated with the laparoscopic approach) or without mechanically morselizing the tumor following its transfer into a laparoscopic bag. This latter process, which destroys the tumor capsule and disrupts internal tumor architecture, may impair subsequent accurate pathology assessment. Taken together, the preponderance of data indicate improved operative safety (i.e., decreased blood loss and operative time) is associated with open adrenalectomy, compared to the laparoscopic approach, for large adrenal tumors (an example of such a tumor is shown in Fig. 3). In contrast, the safety and efficacy of laparoscopic adrenalectomy has been well established for smaller benign tumors, certainly when < 4 cm in diameter, and the laparoscopic/minimally invasive approach should be employed in such cases (Fig. 1).

Primary adrenal malignancy/suspicion for primary adrenal malignancy

Adrenocortical carcinoma is a rare, highly aggressive malignancy (Figs. 4, 5). Adrenalectomy, with *en bloc* resection of involved adjacent tissues (complete/R0 resection), is the standard of care for this cancer, as currently available percutaneous, neoadjuvant/adjuvant chemotherapeutic and radiotherapeutic treatments remain ineffective. In particular, ACC has the potential to produce peritoneal carcinomatosis, a generally untreatable condition in which tumor deposits develop throughout the abdominal compartment. This condition occurs when malignant cells reach the peritoneal cavity, either by direct invasion through the adrenal capsule or when the adrenal capsule is damaged (i.e., during tumor resection or biopsy). Avoidance of carcinomatosis, which carries a particularly poor prognosis, requires extreme

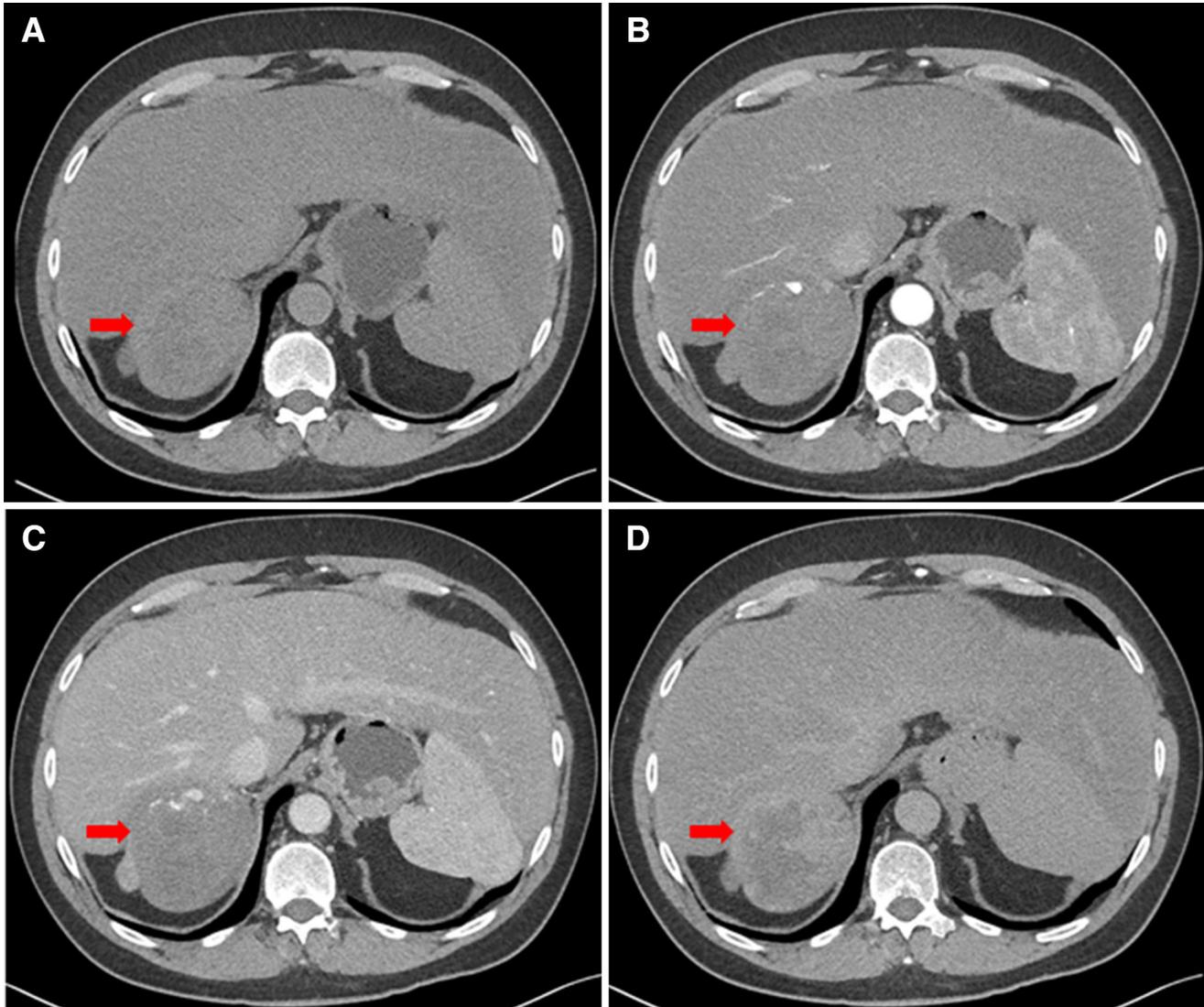


Fig. 3. **A** Axial non-contrast CT image, **B** axial arterial phase (30 s post-injection) contrast-enhanced CT image, **C** axial venous phase (60 s post-injection) contrast-enhanced CT image, and **D** axial delayed phase (15 min post-injection) contrast-enhanced CT image in a 61 year-old man. An 11.0 cm lobulated, heterogeneously enhancing, right adrenal mass is present (red arrows). Given the large size

of this mass, as well as the presence of internal heterogeneity and the absence of benign enhancement characteristics, an open surgical approach was selected. Despite features concerning for malignancy, analysis of the surgical specimen revealed a benign adenoma with associated hemorrhage (illustrating the sensitivity, but not specificity, of CT imaging for indeterminate adrenal tumors).

care to maintain tumor capsule integrity during adrenalectomy. Most experts believe that the absence of tactile sensation inherent to the laparoscopic approach translates to increased risk of tumor capsule disruption and thus to increased risk of carcinomatosis/disease recurrence [10, 13].

A consensus statement made following the 1st International Adrenal Cancer Symposium in 2003 held that “there is no role for laparoscopic removal of a known or likely ACC” [27]. Since that time, a number of studies have sought to define any potential role for laparoscopic

ACC resection. Cooper, et al., for example, reviewed a large series of ACC patients and found that laparoscopic adrenalectomy was associated with higher rates of recurrence, particularly peritoneal carcinomatosis, and that when the data were controlled for tumor stage, open adrenalectomy correlated with improved recurrence-free and overall survival [11]. Studying a large retrospective cohort of patients, Payabyab et al. also found a much higher rate of peritoneal involvement in ACC patients treated with laparoscopic adrenalectomy [13]. A meta-analysis from Autorino et al. found that ACCs treated

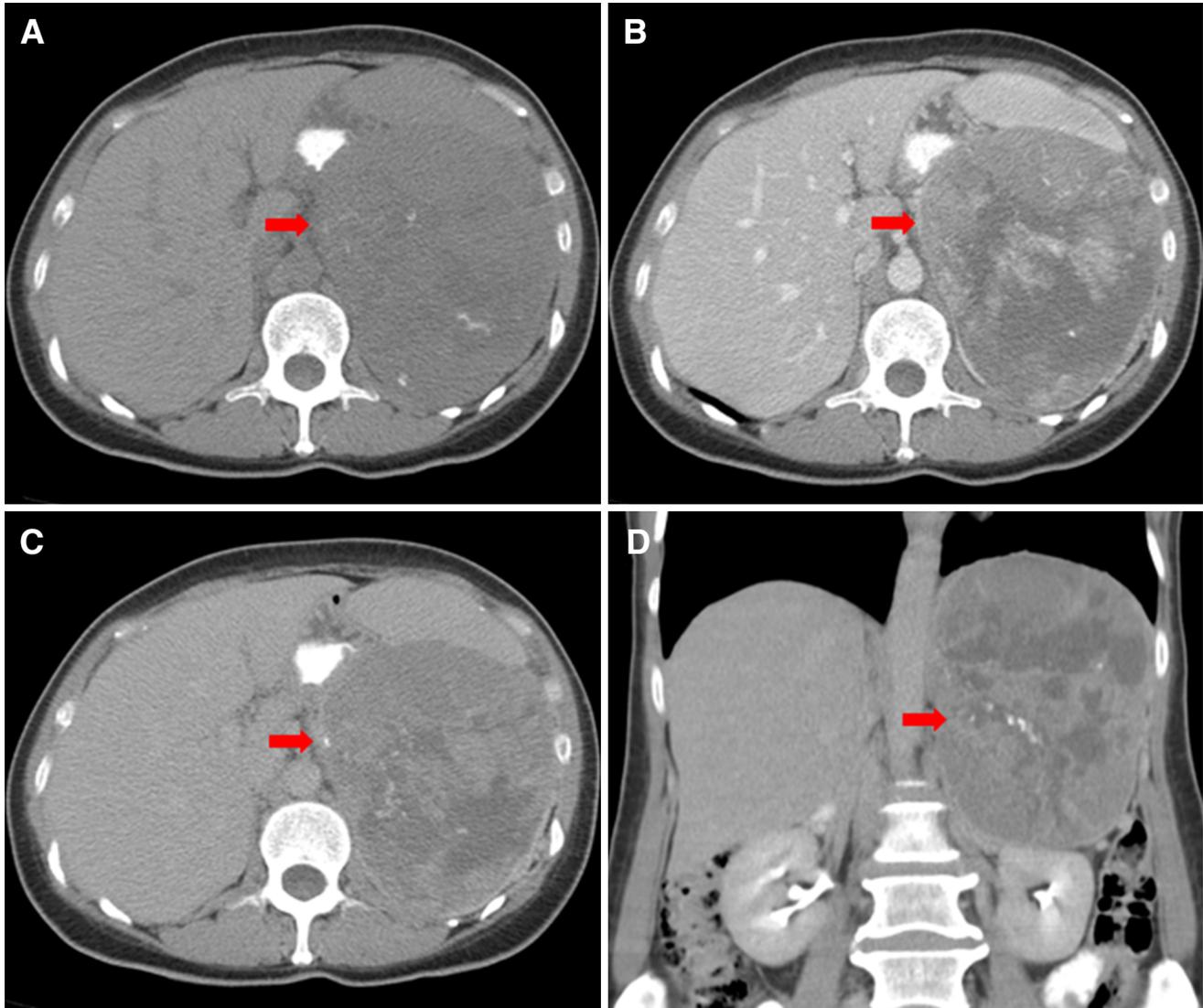


Fig. 4. **A** Axial non-contrast CT image, **B** axial venous phase (60 s post-injection) contrast-enhanced CT image, **C** axial and **D** coronal delayed phase (15 min post-injection) contrast-enhanced CT images in a 57 year-old woman with a large left adrenal mass (red arrows). The large size of this tumor, as well as its heterogeneous enhancement pattern, raise suspicion for ACC and an open surgical approach was

selected. Although difficult to appreciate through CT scanning, this tumor was adherent to the stomach, pancreas, spleen, and diaphragm, leading to resection, or partial resection, of these structures. Successful *en bloc* resections such as this are greatly facilitated by an open surgical approach. Surgical specimen analysis confirmed ACC.

laparoscopically are generally smaller than their laparoscopically resected benign counterparts and no difference in time to recurrence was identified between the laparoscopic and open approaches, although higher rates of carcinomatosis were associated with laparoscopy [12]. A recent study published by Huynh et al. suggests that selection of laparoscopic adrenalectomy for ACC patients could decrease overall survival [28]. Of note, some investigators suggest that relatively small ACCs, for which imaging findings are consistent with noninvasive disease, can be removed laparoscopically without com-

promising oncologic outcome, although such findings represent the minority of published data [29].

Given a generally accepted increase tumor recurrence risk associated with laparoscopic ACC resection, open adrenalectomy, during which direct tumor palpation is used to assess disease extent and preserve the tumor capsule, is the preferred approach for ACC. In light of this preference, preoperative identification of adrenal malignancy becomes critically important to the surgeon. Unfortunately, the preoperative diagnosis of ACC is challenging. In the absence of frank evidence of local

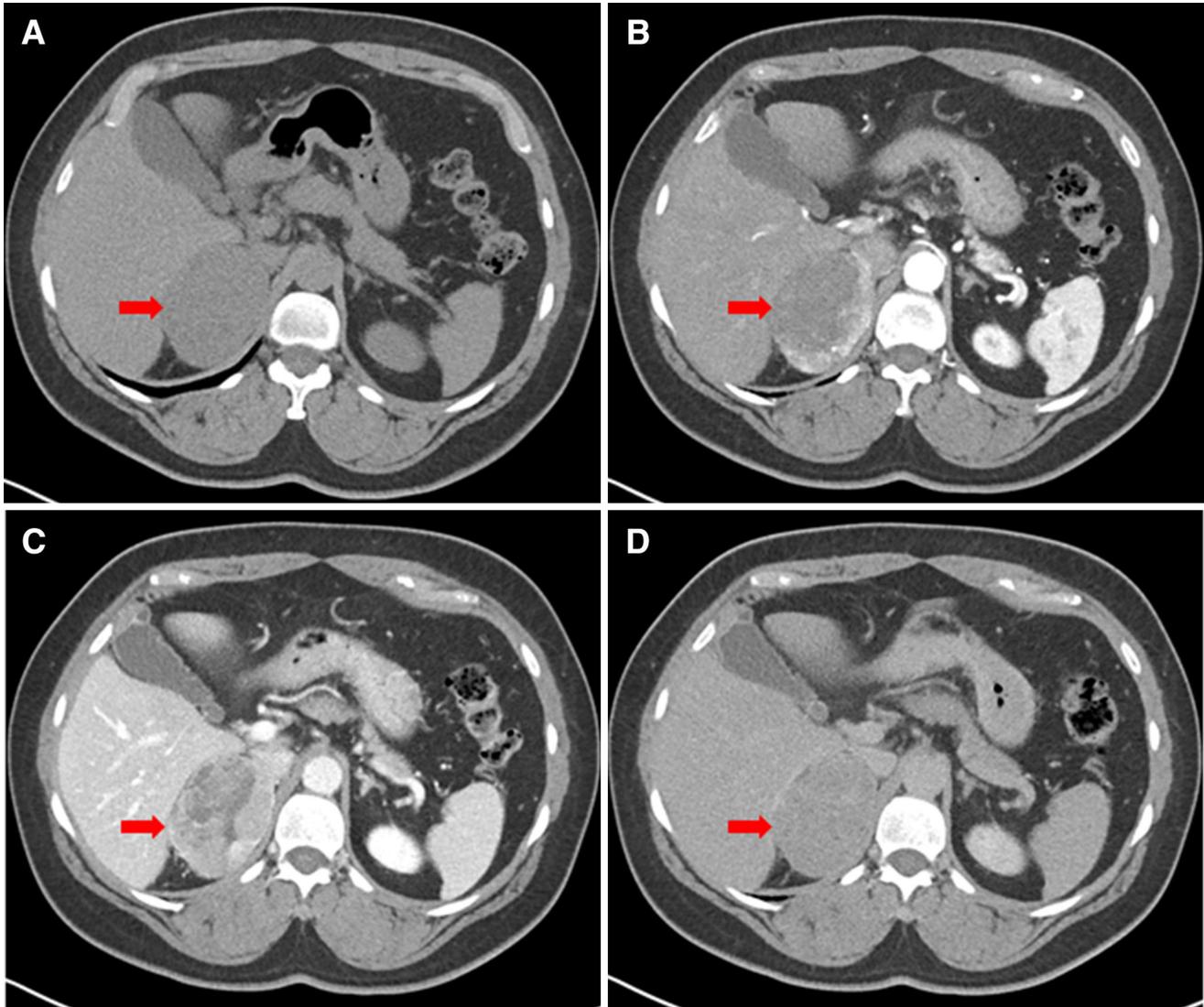


Fig. 5. **A** Axial non-contrast CT image, **B** axial arterial phase (30 s post-injection) contrast-enhanced CT image, **C** axial venous phase (60 s post-injection) contrast-enhanced CT image, and **D** axial delayed phase (15 min post-injection) contrast-enhanced CT image in a 63 year-old woman with an

9.0 cm right-sided adrenal mass (red arrows). The mass does not frankly invade surrounding structures, although its size and heterogeneous features are suggestive of malignancy. An open adrenalectomy was therefore performed. The associated surgical specimen assessment confirmed ACC.

invasion and/or of distant metastatic disease, a diagnosis of ACC cannot be made unequivocally. Preoperative planning is thus dependent on estimation of the risk that an adrenal tumor may represent ACC, and this, in turn, depends on associated imaging features. Adrenal tumor size is one of the key considerations in the preoperative assessment for ACC, as a clear relationship exists between tumor diameter and the risk of ACC. Approximately 5% of adrenal tumors having indeterminate imaging features will represent ACC when tumor diameter reaches 4 cm, while 25% of such tumors > 6 cm will be malignant [26, 30]. Thus, adrenal tumor size plays a critically important role in the selection of operative approach, with tumors > 4 cm in diameter having

indeterminate imaging features generally meriting an open surgery on the basis of associated malignancy risk (Figs. 1, 5). It is important to note that the direct relationship between adrenal tumor size and risk of ACC is limited to tumors having indeterminate internal imaging features (discussed below). Adrenal tumors for which internal imaging features are benign do not demonstrate an association between size and ACC risk [31].

Specific imaging features

Beyond tumor size, a number of CT findings are sensitive for (but not specific to) the diagnosis of ACC. Approximately 87% of ACCs will demonstrate heterogeneous

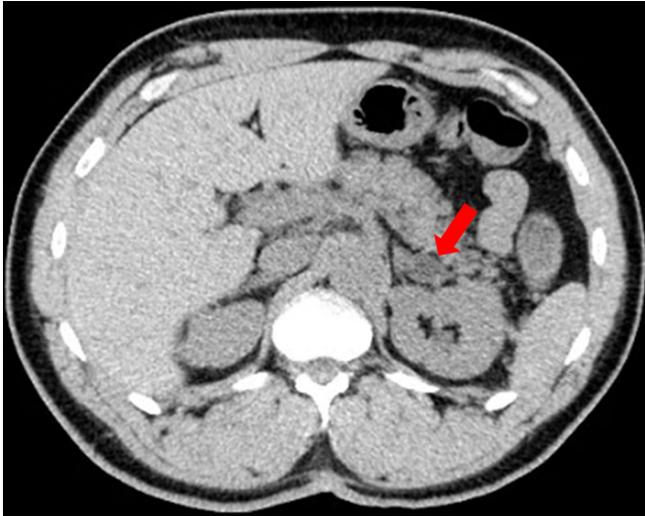


Fig. 6. Axial non-contrast CT image of a 2 cm left adrenal tumor (red arrow) in a 57 year-old man diagnosed with primary hyperaldosteronism. Associated internal enhancement is -5 HU, consistent with a benign adenoma. Given the small size of this tumor and the absence of unusual or aberrant surrounding anatomic features that might impact surgical decision planning, additional CT phases were not obtained. This tumor was successfully resected laparoscopically and surgical specimen analysis revealed a benign adrenal adenoma.

imaging features, with enhancement patterns varying from extensive intra-tumoral heterogeneity (often representing focal necrosis) to predominantly peripheral enhancement [32]. Roughly 26% of these tumors will also contain calcifications [32, 33] and the tumor border may be irregular in shape. Imaging findings characterizing benign adrenal adenomas have been clearly described. For well-defined, homogenous tumors, a maximum non-contrast phase internal attenuation of 10 or fewer Hounsfield Units (HU) is diagnostic of a benign tumor (Fig. 6) [13]. If internal attenuation exceeds 10 HU on non-contrast CT scanning in one or more tumor areas, intravenous (IV) contrast-enhanced venous phase (60 s) and delayed phase (15 min) images are obtained during the same scanning session, so as to further assess for adrenal malignancy. An absolute contrast washout of $> 60\%$, or relative washout of $> 40\%$, between venous and delayed contrast phases is also diagnostic of an adrenal adenoma (Fig. 7). It is important to note that many adrenal adenomas will not demonstrate these benign imaging criteria and the absence of these imaging findings therefore does not preclude a benign diagnosis. Imaging findings consistent with frank infiltration of the peri-adrenal fat and/or invasion into adjacent structures (including tumor thrombus involving local vasculature) are also characteristic of ACC. The presence of metastatic disease is another indicator of ACC, with the liver most often involved and other potential metastatic sites

including the lungs, bones, and regional lymph nodes [30]. Specific additional findings associated with adrenal protocol CT scanning may also provide diagnostic information beyond assessment for malignancy. Areas of internal arterial phase contrast enhancement exceeding 110 HU, for example, are suggestive of pheochromocytoma (Fig. 8), which also tend not to meet contrast washout criteria for benign disease, while identification of internal macroscopic fat is most compatible with myelolipoma (although small foci of such fat may rarely be seen in cases of ACC) (Fig. 9) [14, 22].

Additional considerations

Metastasis from a distant primary site may manifest as an adrenal tumor and may demonstrate imaging features indistinguishable from those associated with ACC. In such cases, differentiation between metastatic ACC and a metastatic non-adrenal malignancy involving an otherwise normal adrenal gland, on the basis of imaging findings may not be possible. Aspiration or core needle biopsy of non-adrenal disease can provide additional diagnostic information in these cases. When biopsy and imaging findings are consistent with oligometastatic disease originating from a non-adrenal primary tumor, but involving an adrenal gland, adrenalectomy may be indicated [30]. Under such circumstances, laparoscopic adrenalectomy may be considered, as metastatic disease to the adrenal gland, unlike ACC, has not generally been associated with increased risk of peritoneal carcinomatosis. Nonetheless, tumor imaging features in these cases, including metastasis size and evidence for associated local invasion, drive selection of operative approach, just as in cases of ACC [34, 35]. Thus, cross-sectional imaging for metastatic disease involving an adrenal gland remains critically important for surgical planning (Fig. 1).

Finally, findings that predispose to the development of intra-abdominal adhesions (e.g., prior surgical intervention near the adrenal to be resected, evidence for prior hemorrhage and evidence of peri-adrenal inflammation) should also be sought by the radiologist, as these findings may favor open surgery. Although not commonly described in the literature, and not viewed as an absolute contraindication to the laparoscopic approach, the presence of extensive intra-abdominal adhesions can obstruct the laparoscopic working space and/or significantly impair laparoscopic visualization, thus necessitating conversion to an open procedure [36, 37]. Further, when excising an adrenal tumor laparoscopically, the risk of large volume, potentially life threatening bleeding, resulting from injuries to the adrenal capsule, difficulty ligating the adrenal vein (which may be very short or tortuous), and/or tearing of the inferior vena cava/renal vein is significant, and assiduous avoidance of such bleeding should be a primary directive [38]. High pre-

Fig. 7. **A** Axial non-contrast CT image (29 HU), **B** axial IV contrast-enhanced phase (60 s post-injection, 123 HU) and **C** axial delayed phase (15 min post-injection, 52 HU) contrast-enhanced CT images of a 3.5 cm left adrenal tumor in a 65 year-old woman diagnosed with adrenal Cushing's syndrome (hypercortisolemia). Non-contrast internal tumor attenuation is > 10 HU, making this adrenal mass indeterminate for malignancy. Comparison of arterial and delayed phase IV contrast images, however, reveals an IV contrast washout of $> 60\%$, consistent with a benign tumor. This tumor was successfully resected laparoscopically and surgical specimen analysis revealed a benign adrenal adenoma.

operative concern for the development of such bleeding should prompt selection of an open approach, through which hemorrhage control is generally most readily achieved. This is also the case when preoperative portal hypertension is present, as associated expanded/dilated retroperitoneal collateral vessel networks may be readily damaged intraoperatively, producing life threatening bleeding [39]. Notation of such features, when present, by the interpreting radiologist is thus of great value to the surgeon (Fig. 1).

Surgical technique: open adrenalectomy

Adrenalectomy, especially in cases for which malignant disease is suspected, is best performed by an experienced surgeon (generally formally trained in endocrine surgery, surgical oncology or in urology). Critical operative considerations dependent on accurate abdominal imaging include the potential need for retroperitoneal lymphadenectomy, the possible need for vascular reconstruction (especially for right-sided tumors for which involvement of the inferior vena cava is suspected) and *en bloc* resection of involved adjacent tissues, potentially including the spleen and involved portions of the ipsilateral kidney, pancreas, liver, small intestine, colon, and stomach [40].

Open adrenal surgery begins with appropriate patient positioning, generally supine (in particular if bilateral adrenal surgery is planned) or in the lateral decubitus position. The incision chosen is generally at least 10 cm long, with specific incision positioning dependent on surgeon preference and on the extent of disease. An ipsilateral subcostal incision is made for patients arranged in a lateral decubitus position, while a midline

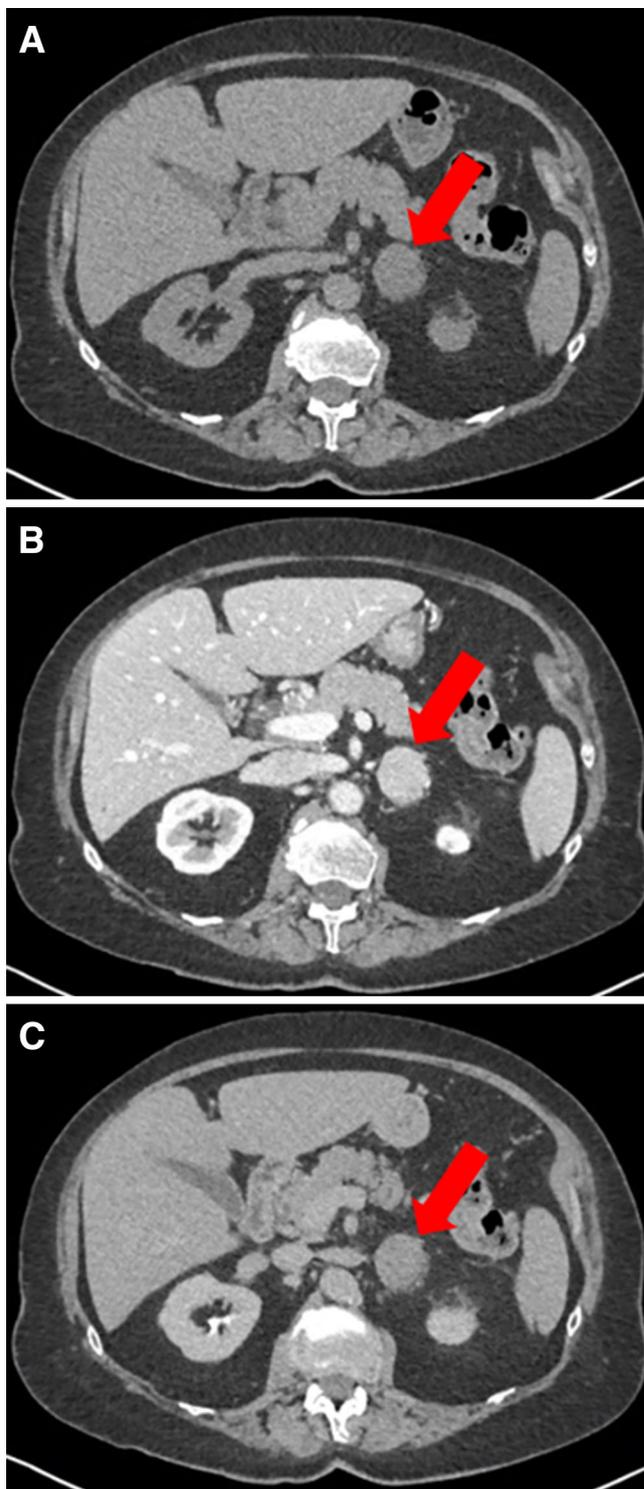




Fig. 8. Axial IV contrast-enhanced CT image (venous phase, 60 s post-injection, 115 HU) of a 2.2 cm left adrenal tumor in a 52 year-old man. Associated internal areas of tumor enhancement of > 110 HU are suggestive of pheochromocytoma and subsequent biochemical testing confirmed this diagnosis. Following initiation of alpha-blocker therapy, this tumor was successfully resected laparoscopically. Surgical specimen analysis revealed an organ-confined pheochromocytoma.

laparotomy incision is made for supine patients. A thoracoabdominal incision can be made if need for access to the supradiaphragmatic vena cava and/or heart is anticipated, which is generally only required when extensive locally invasive disease is present and need for vena caval reconstruction is anticipated [41].

Following entry into the peritoneal space, the adrenal retroperitoneum is accessed by rotating the overlying viscera from lateral to medial. On the right, this entails rotating the liver and upper right colon towards the abdominal midline to reveal the underlying right kidney, adrenal gland, and inferior vena cava. The corresponding maneuver on the left involves rotating the spleen, pancreas, and upper left colon towards the midline to reveal the underlying left kidney and adrenal gland. The gland on each side is then mobilized by carefully dissecting the associated retroperitoneal attachments, including skeletonization and mechanical ligation of the adrenal vein which is usually found coursing from the medial aspect of the gland on each side. This dissection is often greatly facilitated by direct palpation, which enables identification of malignant involvement of adjacent organs and dissectible tissue planes, which is not possible via a laparoscopic approach. Arterial blood supply to the adrenal glands is provided by numerous small feeding vessels, which are generally readily controlled using energy-based cautery technologies and thus, unlike the adrenal vein, do not require specific identification and mechanical ligation. Identification of malignant infiltration from the adrenal gland into surrounding tissues re-

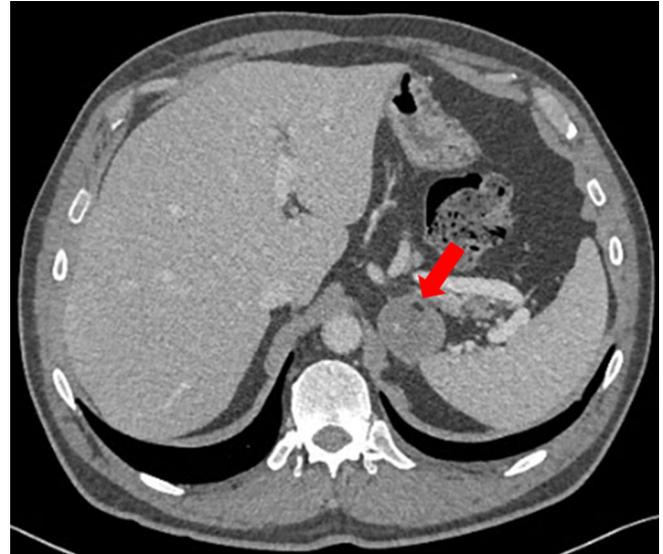


Fig. 9. Axial IV contrast-enhanced CT image (venous phase, 60 s post-injection, 64 HU) of a 4.4 cm left adrenal tumor in a 59 year-old man. Although non-contrast imaging reveals internal attenuation > 10 HU, making this tumor indeterminate for malignancy, a focus of macroscopic fat, which is compatible with myelolipoma, is appreciated (red arrow). Myelolipomas are inherently benign tumors and, in the absence of associated symptoms, adrenalectomy may be deferred in favor of close follow-up (as was recommended in this case).

quires wide *en bloc* resection of involved structures with the adrenal gland, so as to achieve margins negative for disease involvement [40].

An illustrative guide to laparoscopic adrenalectomy

Although the specific anatomy involved differs between left and right laparoscopic adrenalectomies, the basic principles of patient positioning, port placement and adrenal gland exposure are similar between the two sides. Patients are placed in the lateral decubitus position, with the side targeted for resection facing towards the ceiling. Three to five laparoscopic ports ranging in diameter from 5 to 12 mm, depending on the diameter of the corresponding instruments intended for use, are placed through the abdominal wall into the peritoneal space at regular intervals below the costal margin (Fig. 10, top and bottom). The intra-abdominal working space is created via peritoneal insufflation using carbon dioxide gas, which is introduced and maintained via a side channel associated with the first port placed.

Laparoscopic right adrenalectomy

Laparoscopic resection of the right adrenal begins with mobilization of the liver, which overlies the gland. First,

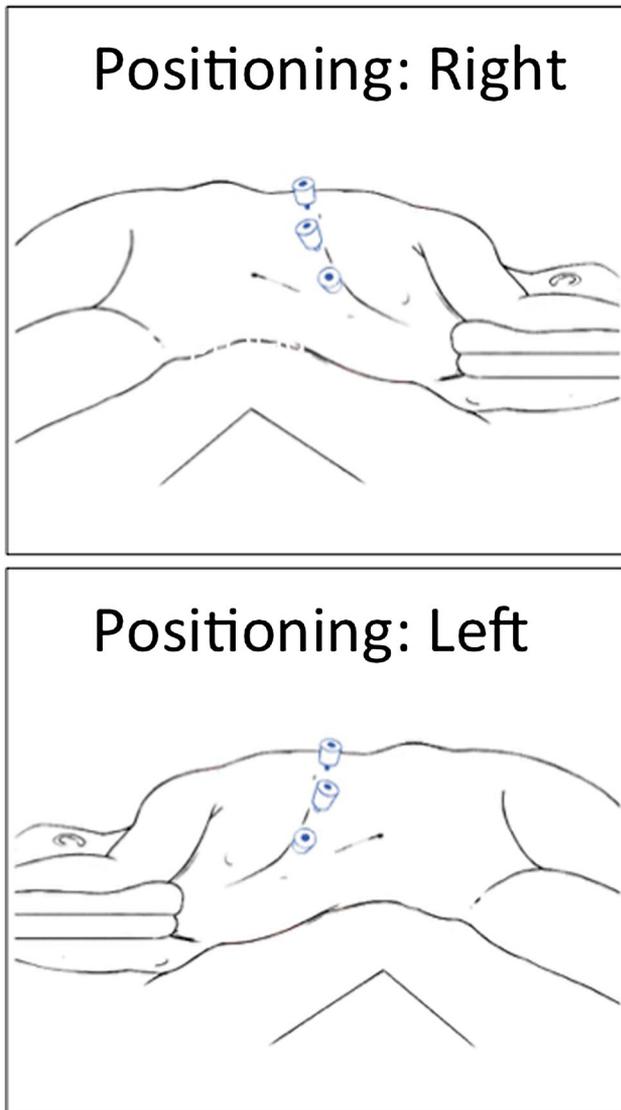


Fig. 10. Lateral decubitus patient positioning for laparoscopic right (top) and left adrenalectomies. Subcostal laparoscopic port locations are shown in each case.

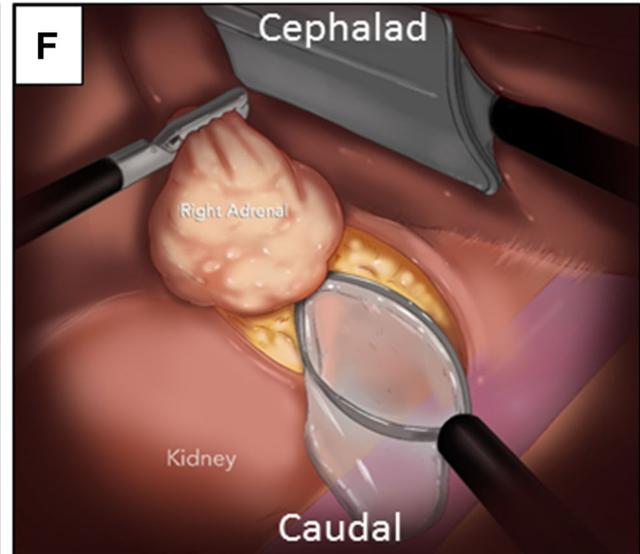
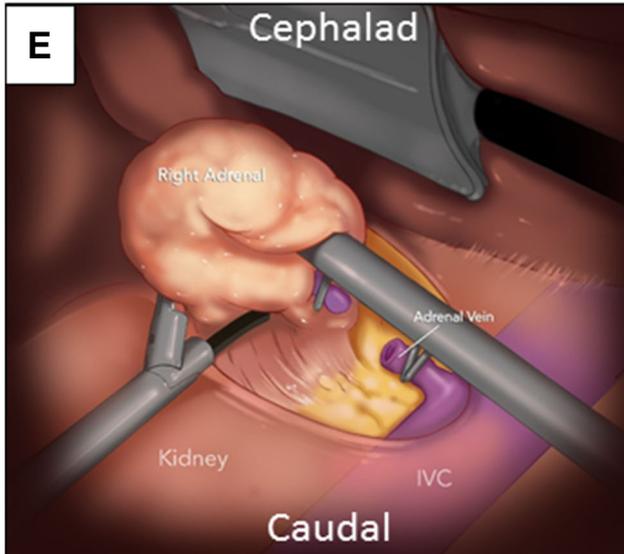
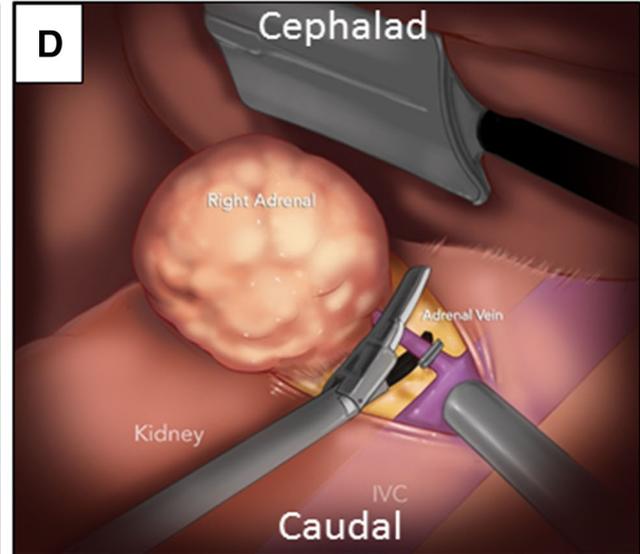
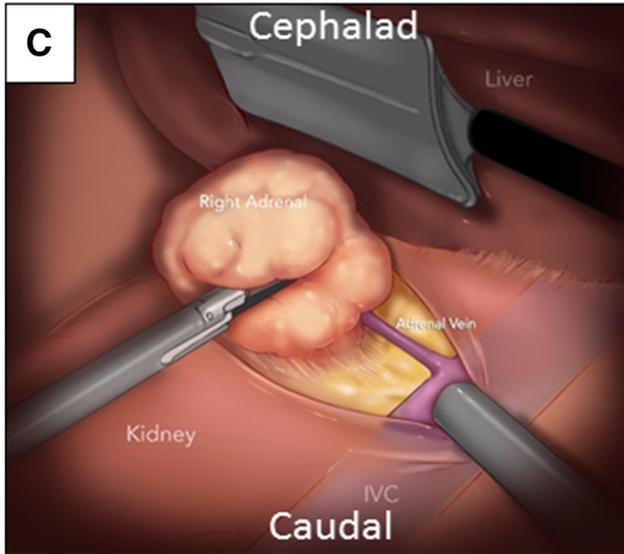
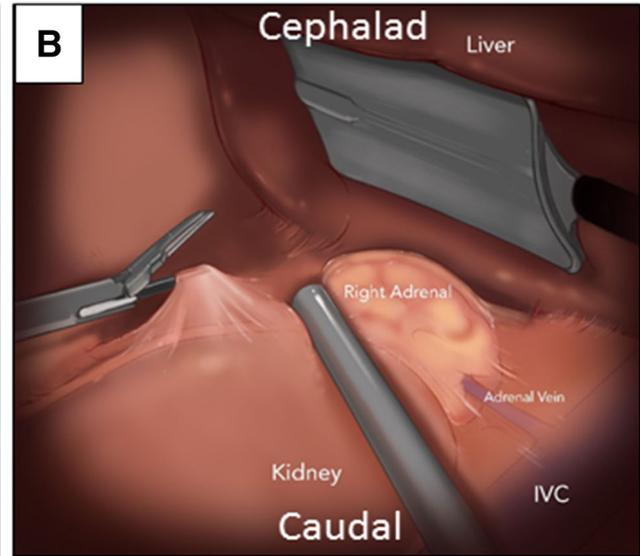
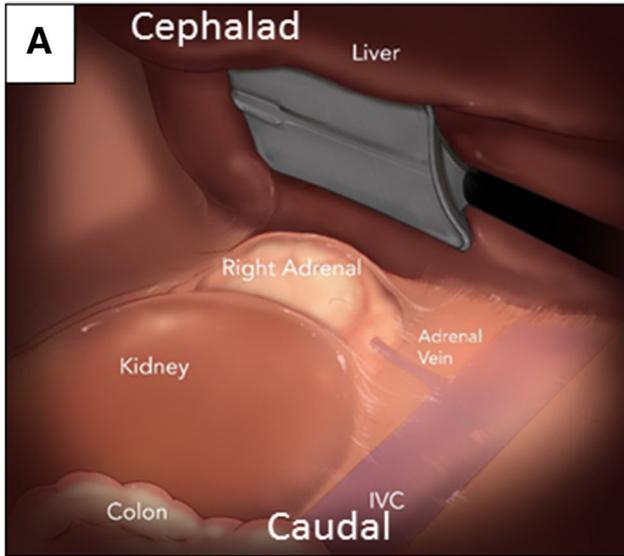
the peritoneal attachments to the inferior and lateral aspects of the liver are lysed, generally using a specially designed cauterizing energy device, to expose the retroperitoneal fat pad between the liver (cephalad) and the right kidney (caudal, Fig. 11A). As these attachments are sequentially lysed, the liver is rotated cephalad using a laparoscopic retractor/paddle, exposing the underlying retroperitoneal/perirenal fat in which the adrenal gland resides (Fig. 11B). Gerota's fascia, a connective tissue layer enveloping the kidney and adrenal, is then incised to expose the gland. The retroperitoneal attachments to the adrenal are then sequentially lysed at, or near, the gland surface, allowing progressive separation of the gland from the kidney inferiorly, the liver superiorly and the inferior vena cava medially. Great care is taken to avoid damaging the inferior vena cava, as caval injury

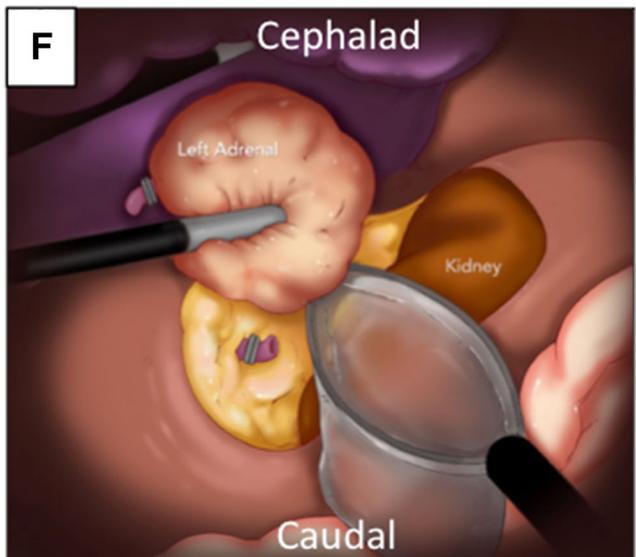
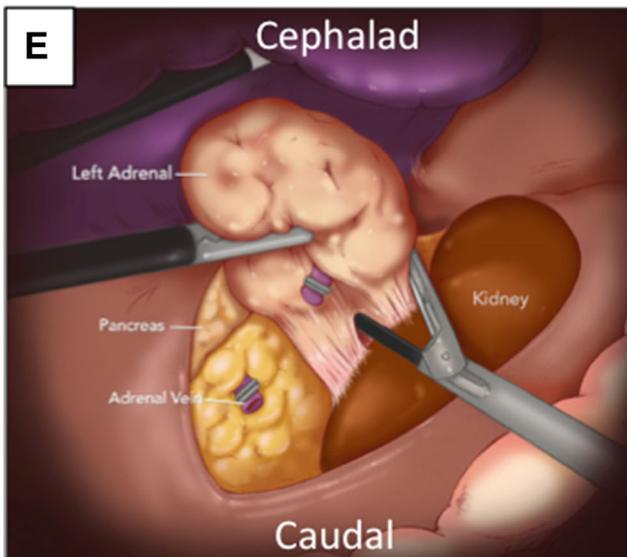
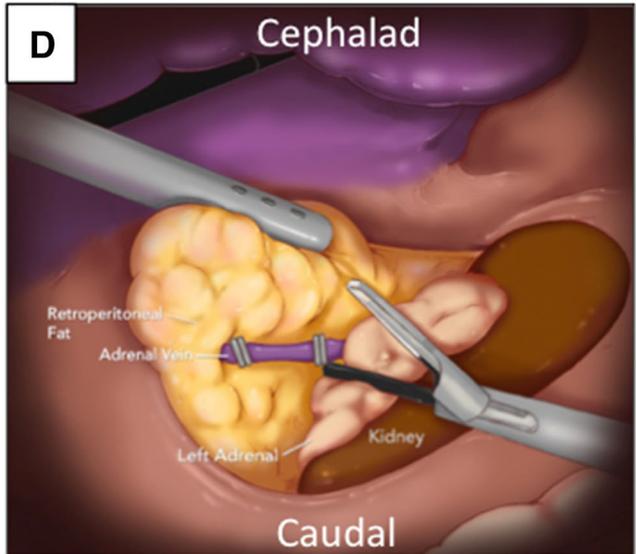
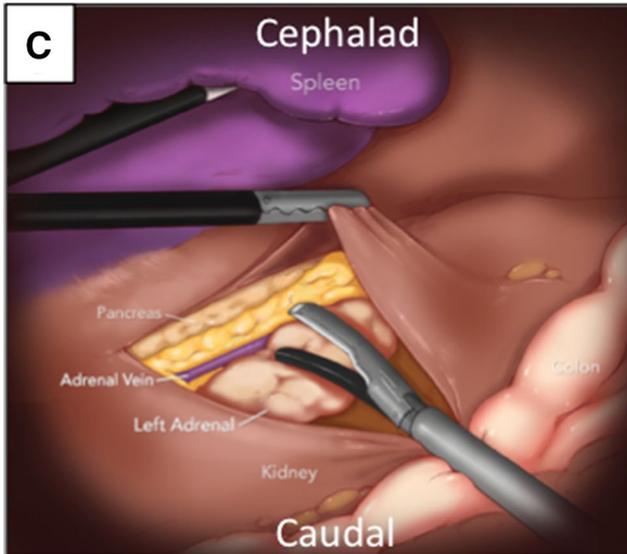
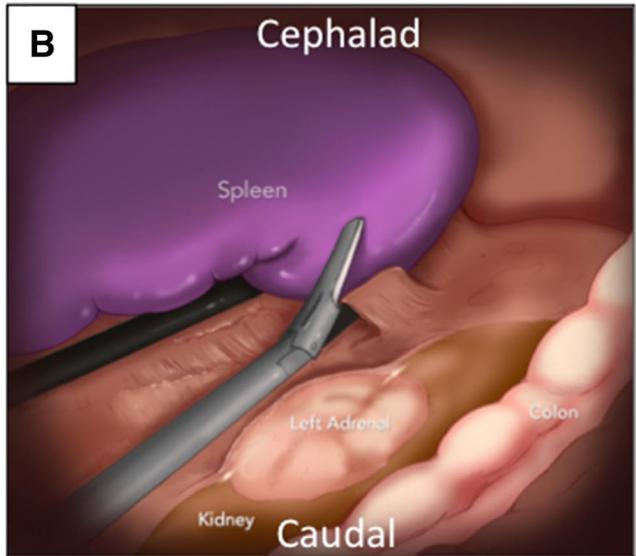
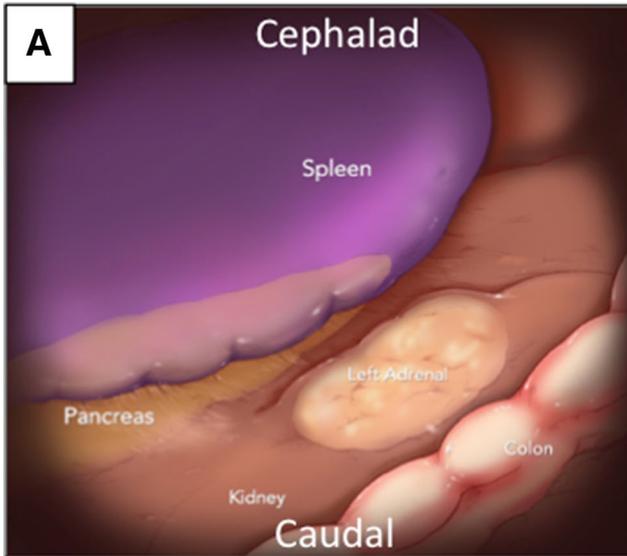
Fig. 11. Illustrative guide to laparoscopic right adrenalectomy. **A** The lateral liver attachments have been lysed, allowing cephalad retraction of the liver using a laparoscopic paddle. The locations of the retroperitoneal organs (the kidney, the adrenal gland and the inferior vena cava/IVC) are shown in silhouette below the peritoneum. **B** The peritoneum and Gerota's fascia are incised to mobilize the right adrenal gland. **C** The medial adrenal gland attachments are carefully skeletonized to identify the inferior vena cava and the right adrenal vein. **D** The skeletonized right adrenal vein is ligated between titanium clips. **E** The remaining retroperitoneal attachments to the right adrenal gland are lysed. **F** The adrenal gland is passed into a laparoscopic bag, which is then removed from the peritoneal cavity through the largest of the port incisions.

may result in very rapid, life threatening hemorrhage. During this dissection, the adrenal vein is identified and skeletonized at the medial aspect of the gland (Fig. 11C). This vein is then ligated, usually mechanically, using a laparoscopic stapling device or titanium clip applier (Fig. 11D). The remaining retroperitoneal adrenal attachments are then lysed, thereby completely freeing the gland (Fig. 11E). The specimen is then passed into a laparoscopic bag, which is pulled through the largest port incision made (Fig. 11F).

Laparoscopic left adrenalectomy

The surgical principles underlying laparoscopic left adrenalectomy are similar to those involved in laparoscopic resection of the right adrenal gland. Following subcostal port placement (Fig. 10, bottom) and peritoneal insufflation, the peritoneal attachments to the lateral aspect of the spleen and the upper left colon are incised, again usually via use of a cauterizing energy device (Fig. 12A, B). This dissection plane is then carried deeply along the abdominal wall to the underlying retroperitoneal floor/muscle. Gerota's fascia anterior to the left renal apex is then incised to identify the upper pole of the left kidney. This dissection plane is then carried deeply to the retroperitoneal floor and laterally to the abdominal wall. These maneuvers allow medial rotation of the spleen and the associated pancreas (situated inferiorly and deep to the spleen) as a single unit, thus exposing the underlying retroperitoneal fat pad in which the left adrenal gland resides (Fig. 12C). The left adrenal gland is then dissected from the surrounding retroperitoneal fat, during which great care is taken to avoid injury to the kidney inferiorly, the pancreas superiorly and the renal vasculature medially. The adrenal vein is identified during the course of this dissection and is skeletonized as it courses from the medial aspect of the gland. The vein is then ligated, generally mechanically, using laparoscopic staple or clip technology (Fig. 12D). The remaining retroperitoneal attachments to the gland





◀**Fig. 12.** Illustrative guide to laparoscopic left adrenalectomy. **A** The spleen is visualized in left upper quadrant. The locations of the associated retroperitoneal organs (the kidney, the adrenal gland and the pancreas) are shown in silhouette below the peritoneum. **B** The lateral splenic attachments are lysed, allowing medial rotation of the spleen and pancreas. **C** The peritoneum and Gerota's fascia are incised to mobilize the left adrenal gland. The medial adrenal gland attachments are carefully skeletonized to identify the left adrenal vein. **D** The skeletonized left adrenal vein is ligated between titanium clips. **E** The remaining retroperitoneal attachments to the left adrenal gland are lysed. **F** The adrenal gland is passed into a laparoscopic bag, which is then removed from the peritoneal cavity through the largest of the port incisions.

are then lysed (Fig. 12E) and the gland is transferred into a laparoscopic bag, which is then removed from the abdomen through the largest port site made (Fig. 12F).

Conclusion

Adrenalectomy is the standard of care when treatment is indicated for an adrenal tumor [42]. Though dissertation of the various modalities available for adrenal imaging is beyond the scope of this manuscript, assessment of imaging characteristics that inform selection of adrenalectomy operative approach is effectively achieved by multi-phase CT scanning (including tumor size, probability of malignant character, identification of local tumor invasion and assessment for local/distant metastatic disease). Thus, a clear mutual understanding between surgeons and radiologists of those CT findings that impact operative approach selection is important. In our experience, such understanding is not always present and thus, in order to address this concern, we have described here those adrenal CT scan features that inform the selection of adrenalectomy approach.

Compliance with ethical standards

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Conflict of interest All authors declare that they have no conflict of interest.

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Ethical approval This article does not contain any studies with animals performed by any of the authors. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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