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How to Read an Abdominal Computed Tomography Scan

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During my residency, our hospital received its first CT scan: a machine manufactured by EMI Ltd., formerly known before 1971 as Electric and Musical Industries, Ltd. The device was named an "EMI-Scanner," and we thought it was wonderful, not in small part due to our knowledge that EMI was the company that recorded and distributed the Beatles and other bands.

Looking back, the limitations of that machine seem mind boggling: it could only scan the brain, each slice took 2 minutes to acquire and process, and for a typical 15-slice head CT, the patient spent 30 minutes on the scan table! To hold the head still during the 2 minutes of scanning, a water filled donut fixed to the scanner enclosed the patient's head. This presented some unusual circumstances. I still have a copy of the radiologist's dictation that says "Cranial Computer Tomography: This examination was attempted on 8/3/76 without success because the patient's head size was too large to fit into the EMI brain scanner waterbag."

How much as changed. How many of your patients have a CT scan during their ED evaluation? Many hospitals report rates of 20% or more. A significant number of these scans are of the abdomen and pelvis. I believe it is important for the emergency physician to have the knowledge to view and interpret these images. We are often able to look at the scan and determine the abnormality before the radiologist has time. We sometimes identify abnormalities due to our clinical knowledge of the patient as opposed to the radiologist who may not have the same information. And viewing the images provides us a better understanding of the patient's condition.

Please enjoy this issue of Emergency Medicine Reports *as the authors teach us how to read an abdominal CT scan.*

—J. Stephan Stapczynski, MD, Editor

Statement of Financial Disclosure

To reveal any potential bias in this publication, and in accordance with Accreditation Council for Continuing Medical Education guidelines, we disclose that Dr. Stapczynski (editor) serves on the speakers bureau for Pfizer. Dr. Farel (CME question reviewer) owns stock in Johnson & Johnson Dr. Fox (author), Dr. Westin (author), Dr. Madoff (peer reviewer), Dr. Moore (peer reviewer), and Dr. Schneider (editor) report no relationships with companies related to the field of study covered by this CME activity.

Introduction

From its origins in the 1970s to today, computed tomography (CT) has evolved into one of the primary diagnostic tools of the abdomen, and it continues this ongoing technological progression every day. When first unveiled by Sir Godfrey Hounsfield in 1972, computed tomography was a revolution in radiological imaging. This revolution continued in the 1990s with the innovation of spiral (or helical) CT, which allowed for more continuous scanning and improved z-axis resolution.[1,2] Spiral CT allowed for better three-dimensional imaging and diminished the disadvantages of previous two-dimensional, uniplanar scans by allowing for increased table speed and more distinct longitudinal resolution. This increase in table speed is valuable in a trauma setting, and also significantly reduces the amount of radiation exposure to the patient for any continuous area. The radiation exposure is further decreased as the pitch (pitch [p] = d/s, where d is table feed per rotation and s is slice thickness) is increased.[2]

Spiral CT works by obtaining a volumetric block of raw data in a spiral rather than a planar manner, with the patient moving in a continuous z-axis direction while the tube and detector array rotate around the patient. This continuous motion allows for a much larger volume to be covered, with less radiation exposure per volume covered when compared with sequential CT. The volumetric data images captured by the CT are described as voxels (the three-dimensional equivalent of 2D pixels, or picture elements). An additional method of increasing the speed of image acquisition is increasing the number of rows of detectors. With more parallel rows of detectors, the number of simultaneous readings can be increased without increasing the heat load of the tube, a limitation of early CT scanners.[2] The fundamental principle in improving resolution and image quality is to utilize the smallest collimation and highest pitch possible.[3] This goal is easier to achieve with multidetector CT arrays than with the standard spiral CT array. Accordingly, the advent of multidetector computed tomography (MDCT) has vastly improved imaging technology, especially as it relates to the representation of vascular anatomy.

Hounsfield Units

In order to differentiate between different types of fluid and tissue in the abdomen, it is important to understand the concept of Hounsfield units (HU) and how they are derived. Historically, the recreated images from CT scanners had a wide range of values of 12-bit digital data, measured in standard transform (ST). The inventor of the original CT, Sir Godfrey Hounsfield, developed a method to standardize the density measurements between different machines. Hounsfield's absolute density scale defined air as the minimum density, with a value of –1000 HU, and placed water as the benchmark of 0. The most dense material in the human body, bone, has an upper limit of +1000 HU. The raw data could be translated to HU by the equation HU = ST scale + offset (e.g. scale = 1.0, offset = -1000).[2] This scale can be applied directly to the analysis of free fluid in the abdomen, especially as it relates to identifying blood. The appearance of blood in intra-abdominal hemorrhage can vary depending on the recency of the bleed, and this can help to determine if there is active bleeding or if clotting has occurred. Clotted blood has a heterogeneous appearance and is generally between 45 and 70 HU. Clotted blood tends to congregate close to the original hemorrhage site, producing the so-called "sentinel clot." Freely flowing blood, however, will have a less dense appearance, and typically ranges from 20 to 45 HU.[4] Blood can also be identified by extravasation of contrast material, which can accumulate in the abdominal cavity or demonstrate sites of vascular disruption.[2]

Contrast Use

Abdominal CT scans can be done without the use of radiopaque contrast agents, termed a non-contrast enhanced CT or NECT. The advantage of NECT is that the intense radiodensity of these contrast agents can obscure areas of abnormality, like small renal or ureteral stones. Conversely, the use of a contrast enhanced CT, or CECT, can provide better distinction between tissues and various structures. Most abdominal CT scans are done with intravenous radiocontrast as this approach helps in the identification of inflammatory and neoplastic processes. Intravenous contrast agents use iodine as the radiopaque agent bound to either an organic (non-ionic) or ionic compound.

Barium sulfate, an insoluble powder suspended in water is a common radiocontrast used to fill the lumen of gastrointestinal

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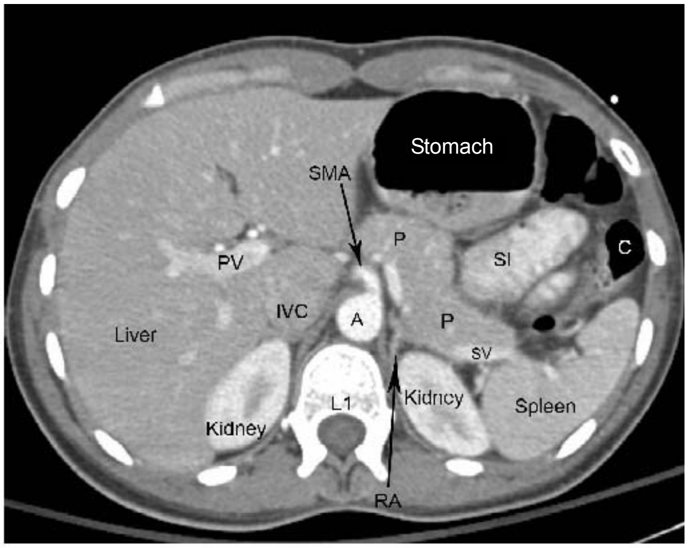
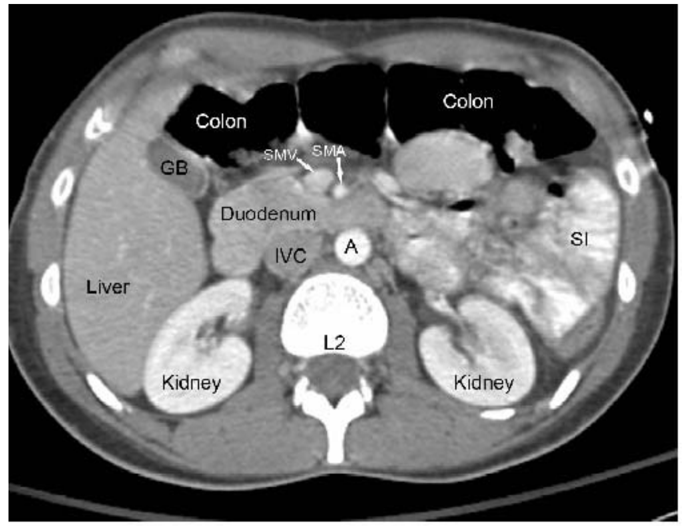
Figure 1. Normal Anatomy at the Level of the First Lumbar Vertebral Body (L1)



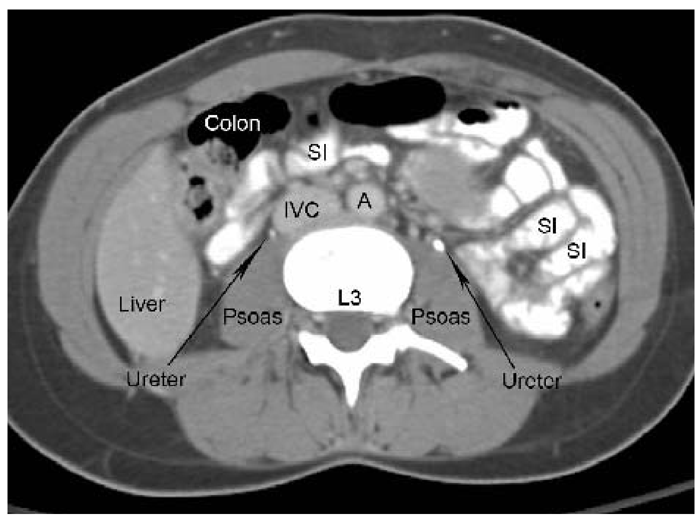
A; aorta, C; splenic flexure of colon, IVC; inferior vena cava, P; pancreas, PV; portal vein, RA; right adrenal gland, SMA; superior mesenteric artery, SI; small intestine, SV; splenic vein.

Figure 2. Normal Anatomy at the Level of the Second Lumbar Vertebral Body (L2)



A; aorta, C; splenic flexure of colon, GB; gallbladder, IVC; inferior vena cava, SI; small intestine, SMA; superior mesenteric artery, SMV; superior mesenteric vein.

Figure 3. Normal Anatomy at the Level of the Third Lumbar Vertebral Body (L3)



A; aorta, IVC; inferior vena cava, SI; small intestine.

structures during radiography. Many hospitals are using a water soluble iodine product (Diatrizoate Meglumine and Diatrizoate Sodium Solution) before CT scanning when visualization of the gastrointestinal lumen is desired. Both agents can be administered by mouth, nasogastic tube, or rectal enema, depending on the structures to be visualized.

The routine use of both intravenous and oral contrast for abdominal CT scanning has been greatly debated. Because CT technology has dramatically improved, it is important to consider the costs versus the benefits of oral contrast using current machines. ED time studies typically find that the use of oral contrast adds 90 to 180 minutes of extra time until the CT scan is completed. Usually it is the clinicians wanting the study done quickly who order the CT scan without oral contrast. Conversely, radiology-based studies on CT helical scan accuracy find that oral contrast improves sensitivity and specificity for a variety of conditions, such as appendicitis, by 2-3%.[5] It is often the radiologist who wants oral contrast to improve his or her interpretive accuracy.

It is beyond the scope of this article to discuss the appropriate use of intravenous and/or oral contrast. There are a variety of protocols that balance the clinician's need for speed and the radiologist's need for completeness and accuracy. Each institution is encouraged to develop an approach for the use of intravenous and/or gastrointestinal contrast according to the patient's suspected clinical condition for which CT scanning is being done.

Radiation Exposure Concerns

An important consideration in the use of CT is the radiation exposure to the patient, especially in pregnant patients and children. Radiation risks are difficult to quantify and predict, and most estimates are based on radiation exposures in the aftermath of the atomic fallout from Hiroshima, Nagasaki, and Chernobyl. In the studies associated with these events, the minimum absorbed dose associated with statistically significant cancer in children is somewhere between 100 and 200 mGy (1 rad = 10 mGy).[6] By comparison, the approximate mean dose of a pediatric abdominal CT scan is 25 mSv (for X-rays, electrons and gamma rays, the absorbed dose [mGy or rad] is equivalent to the equivalent dose [mSv]).[7,8]

The advent of multislice CT has led to a significant improvement in the quality of pediatric CT scans, due to the increase in table speed, which leads to a decrease in artifact, refinement of contrast enhancement, and less need for sedation. However, this improvement in image quality comes at the cost of increased radiation doses delivered to the pediatric patients in question, due to less focused collimation, and it is suggested that tube currents and kilovolts be adjusted to reduce the dose of radiation delivered.[9] In adults, the lowest dose significantly associated with radiogenic risk is higher—approximately 200 mSv—and it cannot be demonstrated that there is any increased risk below 100 mSv.[6,10] However, the fetus exposed in utero is considered to be more sensitive to radiation effects, and diagnostic studies in pregnant women can sometimes be delayed or avoided due to concerns about teratogenic and radiogenic effects. It should be noted, however, that the American College of Obstetricians and Gynecologists has declared, "Women should be counseled that x-ray exposure from a single diagnostic procedure does not result in harmful fetal effects. Specifically, exposure to less than 5 rad has not been associated with an increase in fetal anomalies or pregnancy loss."[11] It is also notable that no single diagnostic procedure results in a dose greater than this limit, even direct CT scans of the abdomen and pelvis, and that scans of more distant body parts result in levels substantially below 5 rad. A single CT of the abdomen (10 slices) results in a mean estimated fetal dose of 2.6 rad (although some studies suggest an even lower mean estimated fetal dose of 8 mGy, or 0.8 rad), while a pelvic CT can produce a mean estimated dose of 2.5 rad.[11,12] For scans of the chest and head, fetal doses are even lower, less than 0.100 rad and less than 0.050 rad, respectively. With such low fetal doses, even repeat scans of the head in trauma or stroke, or chest CT to rule out or follow pulmonary embolism in a pregnant patient pose relatively little risk to the fetus. At these doses, more than 100 head CT or greater than 50 chest CT could be performed before arriving at the 5 rad limit.[11] Although concerns have been raised about the use of CT for the diagnosis of pulmonary embolism in pregnant patients, studies have demonstrated that helical chest CT results in less fetal radiation exposure than ventilation-perfusion (V/Q) scintigraphy.[13] This is important to note, because a survey in the United Kingdom showed that more than 40% of physicians across all specialties were unaware of the differences in fetal dose exposure between V/Q scans and CT.[14]

Systematic Approach

As in any other imaging analysis, it is important to take a systematic approach when reading abdominal computed tomography (CT). Always begin cranial and gradually move caudally. Likewise, assess structures from superficial to deep, first analyzing the tissues or abdominal wall and then progressing to the internal structures. For physicians with limited experience reading CT scans, it is best to begin by following one organ and tracking it through the entire sequence. With experience, the next step is to follow organs that lie in the same transverse plane, such as the liver and spleen, pancreas and adrenals, and the kidneys. As the CT tracks caudally, identify the appropriate anatomical landmarks, such as the celiac trunk, the superior mesenteric artery, the renal arteries, and the aortic bifurcation. Follow the major vessels to assure that the IVC and the aorta are intact and without major pathology.

Abdominal Wall and Intraabdominal Fluid

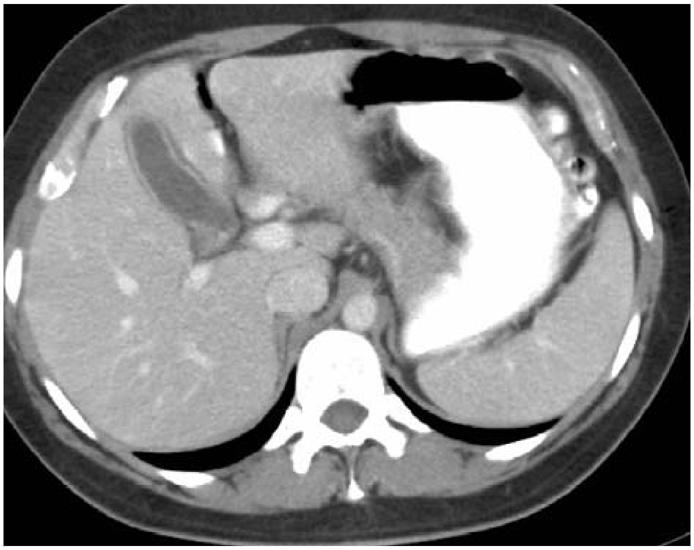
Beginning superficially, check for hernias and other defects in the integrity of the abdominal walls. Assure that the entire abdominal wall is smooth and regular, and identify any irregularities. Also note any thickening of the peritoneum, and whether the thickening is smooth or nodular. Look for fluid collections within the abdominal cavity, and estimate the location and amount of fluid as closely as possible. The amount of fluid can be measured most simply by multiplying the volume of a single voxel (Xmm x Ymm x Zmm) by the number of voxels contained in the space occupied by the fluid. A finer approximation of the volume can be made with smaller voxel units, as there will be less rounding. However, in a scanner with less resolution or with insufficient slice thickness, approximating the shape of the structure may offer a more exact estimation of the volume than the discrete calculation.[2] If there is any fluid collecting in the vicinity of the diaphragm, it is important to ascertain whether the fluid is intrathoracic or intra-abdominal by looking at slices above and below the diaphragm. Generally, pleural fluid is located outside the perimeter of the diaphragm, has a hazy border with peripheral structures, and appears to come in contact with the abdominal wall. Intra-abdominal fluid, on the other hand, is contained by the diaphragm, creates a sharp, distinct border with the diaphragm and surrounding organs, and is located medially. Intra-abdominal fluid accumulation can indicate ascites, hemorrhage, or intraperitoneal abscess, and is of clinical importance regardless of amount.[4]

It is vital to inspect the greater omentum for irregularities, as it often serves as a critical clue in the analysis of abdominal pathology. Nodularity or irregular densities in the greater omentum can indicate metastatic disease, and the position of the greater omentum can often point to a site of trauma or infection by adhering to injured or inflamed organs. Since it is in the transverse plane, it is often difficult to assess the integrity of the diaphragm on CT, but a scan in the correct plane can detect hiatal hernias or traumatic rupture of the diaphragm. Throughout the

Figure 4. Liver Laceration Secondary to Blunt Abdominal Trauma

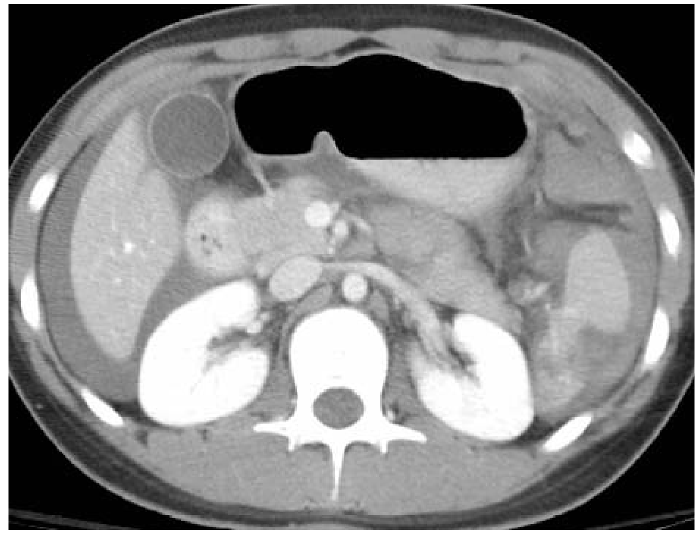
Note active extravasation of intravenous contrast (arrow). The absence of intraperitoneal fluid prevented diagnosis by focused assessment with sonography in trauma (FAST).

Figure 5. Acute Cholecystitis



Note prominent gallbladder wall with pericholecystic fluid

Figure 6. Splenic Laceration with Hemoperitoneum Secondary to Blunt Abdominal Trauma



Note free intraperitoneal blood surrounding both the spleen and liver.

inspection, be alert for enlarged or abnormal lymph nodes, and note their location and size.

Liver and Biliary Tract

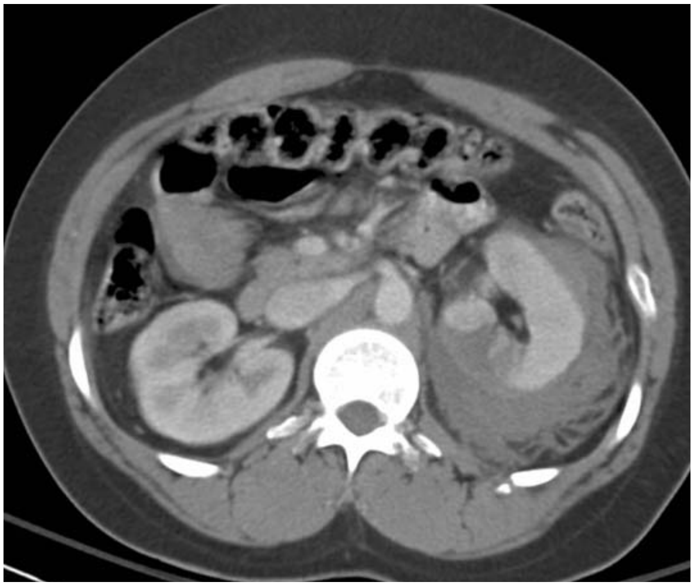
Moving caudally from the diaphragm, next survey the liver and spleen. When using intravenous contrast imaging, there are several important phases in assessing liver function and pathology. The early arterial phase occurs ~18-25 seconds after the injection of a bolus of contrast, and true to its name, is optimal for observing hepatic arterial angiography. Approximately 35-40 seconds post-contrast infusion, the late arterial (sometimes called portal venous inflow) phase begins, and this window is ideal for identifying and categorizing hypervascular tumors. Next, the portal venous, or parenchymal predominant phase begins at ~70 seconds. This is the standard contrast view, which will be used in the vast majority of abdominal CT scans. As indicated by the name, this phase maximally enhances the hepatic parenchyma. The parenchyma should appear homogenous and without notable lacerations or other lesions. Lacerations can be identified by active extravasation of intravenous contrast. (*See Figure 4.*) Sometimes an equilibrium (delayed) phase can be added to more precisely represent a suspicious hepatic mass. When assessing the liver, it is important to note the overall density, which is normally several HU greater than spleen or muscle. Hypodense areas generally indicate fatty infiltration, but may also occur in other settings, such as infection, malignancy, or hepatotoxicity secondary to toxic ingestion.[2] In addition, evaluate whether the surface of the liver is well-defined, and identify any regions of nodularity or blurred borders.

After scrutinizing the liver, the next contiguous structure is the gallbladder. The gallbladder is normally situated in the gallbladder fossa, a depression on the inferior surface of the liver. It is important to identify certain landmarks and specific anatomy of the gallbladder. The fundus is most distal to the common bile duct, and generally protrudes just below the inferior border of the liver. The gallbladder body is routinely in close proximity to the duodenum and hepatic flexure of the colon. The cystic duct is joined to the body of the gallbladder by the gallbladder neck, which is generally located near to the right hepatic portal vein. After leaving the gallbladder, the cystic duct, which is generally only 2-4 cm in length, merges with the common hepatic duct, forming the common bile duct. Completing the biliary tree, the common bile duct joins with the pancreatic duct and enters the duodenum through the ampulla of Vater, regulated by the sphincter of Oddi. Begin by examining the borders and wall of the gallbladder. The borders should appear sharp and distinct, and the wall should be thin and smooth. If the gallbladder wall is thickened, (*see Figure 5*) it can indicate a variety of pathologies, the most common of which are cholecystitis, hepatitis, or major organ failure. Similarly, nodularity or disruptions in the gallbladder wall can signify malignancy, perforation, or abscess. After scanning the walls, inspect the interior of the gallbladder for any abnormalities in lucency, which can indicate fluid collections or stones. Gallstone density can run the spectrum from hypodense to hyperdense, depending on the composition of the stone. Although CT is not as sensitive as ultrasound in revealing gallstones, calculi can be detected with relative accuracy.[4]

Spleen

The spleen generally appears in the same plane as the liver, and can be evaluated simultaneously. Evaluation of the spleen can appear daunting, but it can be broken down into several key areas. Splenic volume can be computed quite accurately on CT, but this is often of limited clinical value, due to the fact that splenic size can be quite variable. Although the mean size is 150 cm^3 in adults, there is a wide range, both within the population and even in a single patient, depending on age, nutritional and fluid status, and body habitus. Instead of using size and volume to assess splenomegaly, the contours of the spleen can often offer an alternative means of

Figure 7. Renal Injury Secondary to Blunt Abdominal Trauma



A moderate amount of perinephric hemorrhage is present.

diagnosis. While a normal spleen generally has a concave visceral surface, in splenomegaly the surface often inverts and takes on a convex appearance. Furthermore, the surface of the spleen is often irregular and frequently has depressions and grooves on its surface that can be mistaken for lacerations. The principal method of differentiating between normal indentations and pathologic lesions is the presence or absence of perisplenic hemorrhage. In the case of splenic infarction, clearly defined, wedge-shaped, hypodense lesions will appear adjacent to the splenic capsule. (*See Figure 6.*) Of interest is the relative mobility of the spleen. Although the spleen is generally located in the left upper quadrant, a spleen located on the long mesentery may drift from its usual location and can be found in virtually any intraperitoneal position within the abdomen or pelvis. As a result, an ectopic spleen can be mistaken for a tumor or other mass if the reader does not recognize and account for the absence of the organ in its usual site.[4]

Pancreas and Adrenals

Proceeding caudally from the gallbladder, the pancreas and adrenals lie in approximately the same plane, and therefore can be analyzed simultaneously. To assess the pancreas, first determine if the borders are well-defined and the size appears to be proportionate to other abdominal organs. A lumpy or pitted border or a mass that appears ragged, uneven, heterogeneous, and/or hypoenhancing and/or obstructs the biliary tract is highly suspicious for malignancy. Pancreatic size is variable and is therefore difficult to assess independently, but in general an anteroposterior measurement > 3.4 cm or a craniocaudad measurement > 4.6 cm of the head of the pancreas (the most common site of pancreatic adenocarcinoma) is concerning.[2,4]

The most important indications for imaging of the pancreas are generally suspicion of tumor or acute pancreatitis. Although the same protocols employed to identify malignancy can be used to evaluate for acute pancreatitis, an acute abdomen protocol can also be utilized, and is generally adequate. If there is ductal involvement in pancreatic neoplasm, it can mimic acute or chronic pancreatitis in both its clinical and radiologic presentation (dilation of the pancreatic duct, calcification of pancreatic tissue), so it is important to differentiate between the two disease processes. Generally, pancreatitis will not demonstrate the peripancreatic inflammatory changes of the mesenteric fat, fluid collection around the pancreas, or lymphadenopathy that can be associated with pancreatic neoplasms. Destruction of retropancreatic fat may be seen in both carcinoma and chronic pancreatitis, but is generally not present in acute pancreatitis.[4]

Kidneys

Proceeding caudally from the pancreatic plane, the profile of the kidneys should appear smooth and elliptical, with an anteromedial concavity produced by the vascular pedicle. The normal renal parenchyma varies in attenuation according to the patient's level of hydration, generally ranging between 30 and 50 HU on NECT. Surrounded by the parenchyma is the renal sinus, which holds the renal vasculature, lymphatic ducts, pelvis, and calyces, and is filled by fatty tissue. Although the cortex and medulla are virtually indistinguishable on NECT, there is visible delineation of the cortex and medulla during the nephrogenic phase of renal contrast. The left renal vein passes anterior to the aorta and posterior to the superior mesenteric artery and vein on its path to the inferior vena cava, and it is discernibly longer than its counterpart. The right renal vein is shorter and follows a more direct course straight to the kidney.[15] Once structural abnormalities have been assessed on NECT, contrast is often required for certain studies.

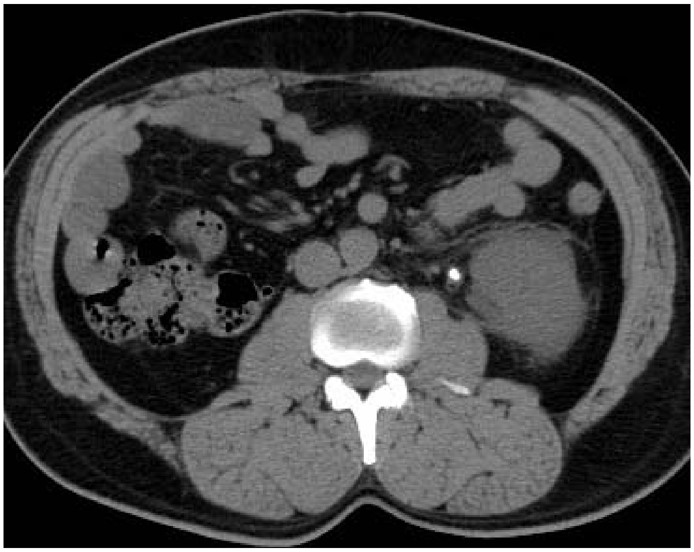
After the initial NECT images are acquired, there are several stages of renal contrast, beginning with the arterial or cortical phase (CP), which occurs between 25 and 80 seconds after contrast injection. This phase is useful for analyzing the renal vasculature and identifying obstruction or stenosis in the renal arteries and veins. The CP is especially useful for CT angiography (CTA) and the generation of three-dimensional (3D) images of the vasculature.[2]

The next stage, the nephrogenic phase (NP), takes place between 80 and 120 seconds following contrast administration. This phase generally is considered to be the best stage for identifying small renal masses. This is important, since the number of renal malignancies identified as incidental findings has increased dramatically in recent years. Some studies indicate that the use of CT and ultrasonography (US) has identified five times as many small cancers (< 3 cm) as before.[2] The nephrogenic phase also demonstrates well renal injuries, such a lacerations and perinephric hemorrhage. (*See Figure 7.*)

The final stage of contrast evaluation begins approximately 2-5 minutes after injection, and is known as the excretory phase (EP). During this phase, the calyces, infundibula, and renal pelvis can be assessed, and it is during this phase that calculi and tumors within the collecting system can be optimally identified.[2] It is important to note if there is symmetric excretion of contrast or if there are filling defects causing asymmetry.

Standard abdominal CECT are normally acquired during the

Figure 8. UPJ Stone



Renal stone located at the left ureteropelvic junction

Figure 9. Left Hydroureter

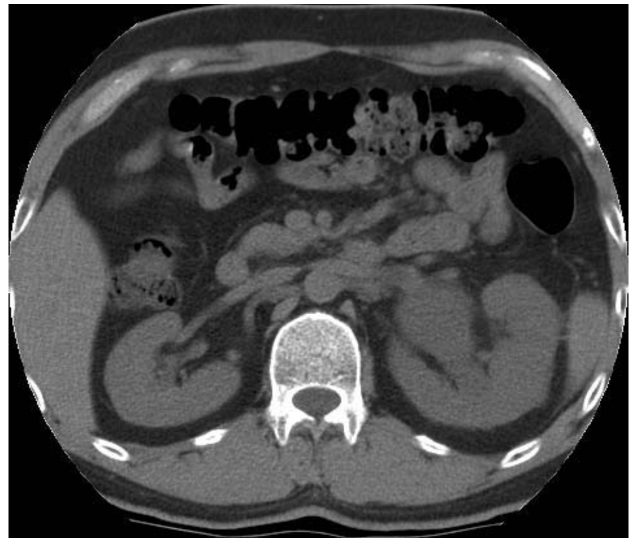
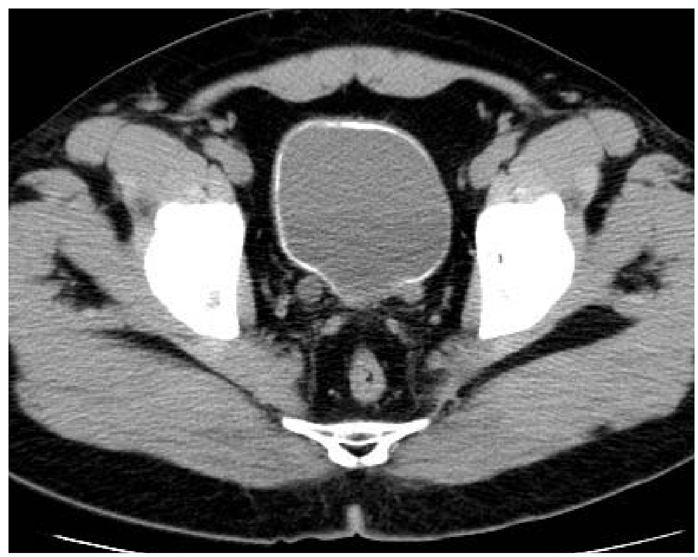


Figure 10. Bladder Wall Calcification Due to Shistosomiasis

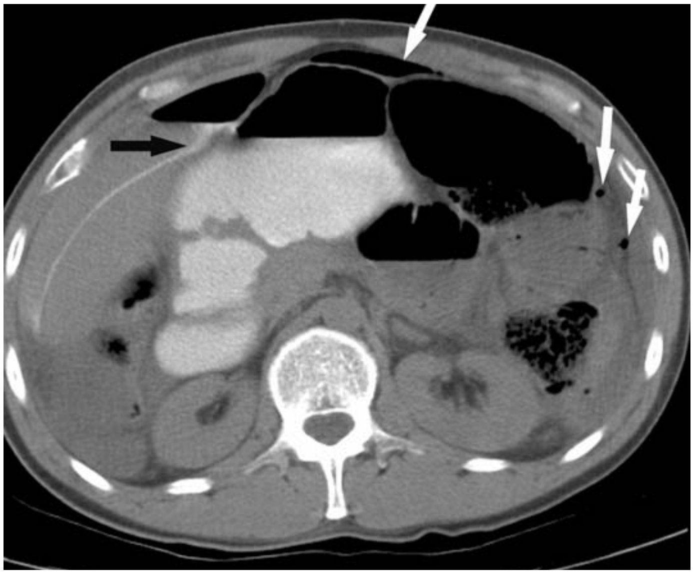


late CP or early NP, which can make certain defects difficult to analyze. As a result, incidental findings or an unclear diagnosis on NECT or standard abdominal CECT may necessitate a dedicated renal CT at a later date.[2]

Although intravenous urography (IVU) and retrograde pyelography are commonly used for the evaluation of hematuria and flank pain, CT remains an important and often superior imaging modality in the kidneys, ureters, and bladder. Indeed, NECT or CT urography with intravenous contrast can arguably replace IVU for nearly all indications of renal, ureteral, and bladder imaging. One of the most common ureteral issues addressed by CT is urolithiasis, for which NECT is still the preferred imaging technique.[4] In the past, IVU has been used quite frequently for diagnosis of urolithiasis, but in the last few years, the evidence has been mounting in support of NECT replacing IVU as the preferred definitive study. Studies have shown CT to have superior accuracy compared to IVU in diagnosing ureteral stones by both direct signs (98.8% vs. 79.3%, respectively) and the combination of direct and indirect signs (100% vs. 90.3%, respectively).[16] In addition, patient management issues such as time management, use of contrast, and cost lean in the direction of CT over IVU. Although there is often little difference in the direct costs of the two studies, indirect costs are often lower with CT, due to decreased examination time (average in-room time of 23 minutes with CT, compared to 1 hour and 21 minutes with IVU), lack of contrast delivery, and the not inconsequential risk of adverse reactions (mild to moderate reactions seen in 5% of patients, often necessitating additional treatment and/or time in the emergency department), and the ability to forego preliminary KUB and US studies if necessary or desired. As a result, NECT is now preferred over IVU by many authors due to a higher diagnostic accuracy and an advantageous cost profile resulting from a more effective, quicker, less expensive, and less risky study.[17] Of course, KUB and US are usually the least expensive and easily available studies, but CT can often provide the best definitive study in the case of equivocal radiographic or sonographic signs, or a negative US or KUB with strong clinical suspicion. Indeed, although ultrasonography can approach 96% sensitivity in ideal circumstances, it can be extremely operator dependent, and direct visualization is not always possible. In comparison, NECT can identify stones with a sensitivity and specificity of 98% to 100%, irrespective of size, location, and type of stone.[18]

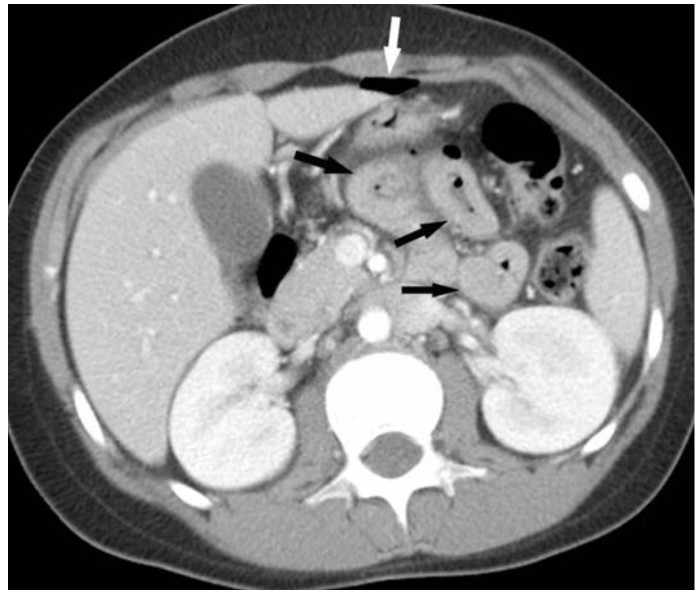
Nearly all renal calculi are hyperdense on CT, and one of the best initial indications that a hyperdense focus is a stone that has passed into the ureter is the “rim sign.” The rim sign is a ring of soft tissue enveloping a calcification within the ureter, signifying inflammation within the ureteral wall. (*See Figure 8.*) This sign can distinguish between a ureteral stone and a phlebolith, which can be mistaken for each other. Phleboliths lack the rim sign and

Figure 11. Duodenal Perforation



Duodenal perforation with free intraperitoneal air (white arrows) and extravasation of oral contrast material (black arrow).

Figure 12. Jejunal Perforation Secondary to Blunt Abdominal Trauma



Note thickened jejunal loops (black arrows) and free intraperitoneal air (white arrow).

often have a lucent center and a "comet tail."[19] Although the rim sign is seen in more than 90% of small renal stones (< 4 mm diameter), other signs are tremendously important to note when assessing ureterolithiasis, especially signs of obstruction. In fact, when hydroureter is noted on CT and combined with either ipsilateral perinephric or periureteric stranding, the positive predictive value is 98% in detecting a stone. When neither of these signs are present, ureterolithiasis can be excluded with a negative predictive value of 93%. With those highly significant numbers, CT accuracy is considered to be vastly superior to the results seen with IVP or ultrasound.[20]

While assessing the ureters and bladder, it is important to look for not only obstruction, as with stones, but to evaluate the integrity of the ureteral and bladder walls. Ureteral dilations may be subtle, or they may be readily apparent. (*See Figure 9.*) The bladder wall should appear smooth and thin without dilations or calcifications. Bladder wall calcifications can be due to shistosomiasis, primary carcinoma of the bladder, alkaline encrustation cystitis, tuberculosis, cyclophosphamide-induced cystitis, and amyloidosis. (*See Figure 10.*)

Stomach and Intestines

In imaging of the gastrointestinal tract, CT has taken a backseat for many years to endoscopy and barium studies. However, with the advent of spiral CT, it is emerging as a valuable addition to the clinician's diagnostic arsenal. Although endoscopy continues to be the most accurate method of diagnosing gastric carcinoma and mucosal diseases, spiral CT is superior in the assessment of intramural disease processes such as submucosal gastric masses, which may show minimal mucosal involvement.[2,4] As such, in the routine evaluation of an abdominal CT, it is important to pay attention to the definition and thickness of the gastric walls. Abnormal thickening of the gastric wall or folds may signify underlying pathology, especially if the thickening is asymmetric or in the general proximity of an unidentified mass or abnormality. As in the analysis of other organs and tissues, it is also important to assess the definition and regularity of the wall contours and account for any aberrations. It is possible to diagnose gastritis or gastric ulcers in this manner with CECT, generally using water contrast. The attenuation of the submucosa of the gastric walls often will be reduced in gastritis, due to edema or inflammation, while the mucosa may be enhanced, causing a "target" or "halo" sign. In addition, there may be wall thickening and hypertrophy of the gastric folds. Wall thickening also may be seen in gastric ulcers, perhaps leading to a reduction in the intraluminal space. Ulcers may also penetrate nearby organs or lipid deposits, and free air may be present secondary to perforation.[4]

While CT is being used more often as a primary imaging technique for gastric pathologies, it is in the small bowel and proximal colon where spherical CT truly comes into its own. The area from the duodenum to the transverse colon is particularly difficult to image endoscopically, and recent improvements in contrast techniques have vastly improved CT visualization of the small intestine.[2] Although small bowel follow through (SBFT) and barium studies still dominate in certain areas of diagnosis, CT is more suitable for identifying extraluminal disease and in the patient with a surgical abdomen.[4] Even in areas where barium studies have certain advantages, such as the identification of intestinal ulcers and polyps, the improvements in spherical CT resolution have made it an increasingly useful tool. Ulcers and polyps can be identified with remarkable accuracy by pinpointing areas of intestinal wall enhancement on CECT. Enhancement of the section surrounding a lesion indicates an underlying pathology, whether it is inflammatory or neoplastic, and as an incidental finding can indicate the need

Figure 13. Acute Appendicitis

White arrow shows enlarged appendix and periappendiceal fat stranding.

for further study.[2] Intestinal wall thickening or luminal constriction can be additional clues to duodenal ulceration and, as in the stomach, infiltration into surrounding fat and organs or free air can signal perforation.[4] (*See Figures 11 and 12.*) Similar to analyzing other vessels and luminal organs, distention or stenosis usually signifies an underlying pathology, and the length of the intestine should be evaluated for continuity and consistent intraluminal area.

As with the rest of the gastrointestinal tract, inspection of the lumen and walls for distortion, distention, or changes in attenuation is important. Alterations in the regular pattern of the haustra or changes in the contour of the colonic wall, as well as distention of the colon with air or fluid should all be noted. Occasionally, air or blood can be visualized within the colonic wall, indicating ischemic bowel wall. Diverticula can be observed as outpouchings of the colonic wall containing air, contrast, or stool. On CECT, the previously mentioned halo or target sign can be observed when the inner and outer rings of the bowel wall are enhanced, while the middle ring shows minimal or no enhancement due to submucosal edema. Tapering or stenosis may also be apparent, as well as twisting of the mesentery.[4]

Diverticula are a fairly common finding in the elderly population, occurring in up to 80% of people by age 85. Diverticulosis, while not concerning in itself, can develop into diverticulitis in 10-35% of patients with documented diverticula, and up to 25% of these patients may need surgery.[21] Diverticulitis can have classic clinical symptoms, including left lower quadrant pain and tenderness, fever, and leukocytosis, but it can also present with nonspecific symptoms, which may make imaging necessary.

Although barium enema was previously thought to be a reasonable alternative to CT, it is now generally accepted that this exam has key deficiencies in comparison to CT. In analyzing an abdominal CT for diverticulitis, several important signs have been identified, with varying degrees of sensitivity and specificity. In one study, 96% of patients showed bowel wall thickening (sensitivity 96%, specificity 91%) and 95% demonstrated fat stranding (sensitivity 96%, specificity 90%), and of course most (91%) patients revealed diverticula. These three signs are regarded by many authors to be the most common and reliable indicators in diagnosing diverticulitis, and generally occur between 70% and 100% of the time.

Other specific but less sensitive signs included fascial thickening (sensitivity 50%, specificity 100%), free fluid (sensitivity 45%, specificity 97%), inflamed diverticula (sensitivity 43%, specificity 100%), free air (sensitivity 30%, specificity 100%), and the "arrowhead" sign (sensitivity 16%, specificity 99%). Overall, thin-slice helical CT with colonic contrast has both a 99% sensitivity and specificity for diverticulitis.[21]

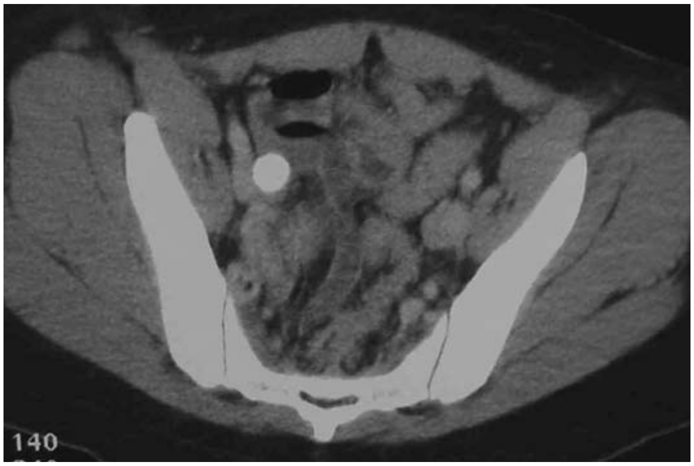
Appendix

During examination of the small and large bowels, the appendix should be assessed as a matter of routine in any patient with acute abdominal pain, especially with the classic symptoms of right lower quadrant pain, nausea, vomiting, and leukocytosis. In determining whether a CT scan is necessary for the diagnosis of acute appendicitis, some authors recommend using the Alvarado scores as a guideline. Patients with Alvarado scores of 3 or less can generally forgo CT scanning as the incidence of appendicitis in this population is < 5%.[22] Conversely, for patients with an Alvarado score of 7 or greater have a greater than 70% incidence of acute appendicitis, so surgical consultation before CT scanning is recommended. It is with Alvarado scores of 4 to 6, where the incidence of acute appendicitis is about 30 to 40% where CT scanning is most useful.[22] In patients with these equivocal scores, CT scans have a sensitivity for acute appendicitis of 90+% with a specificity of 95%.[22]

Overall accuracy of CT in the diagnosis of appendicitis varies, but is generally quite high. One larger review found a sensitivity of 96.5% and a specificity of 98%, with a positive predictive value of 94.5% and a negative predictive value of 98.8%, and an overall accuracy of 97.6%.[23] Another study showed sensitivities of 88-100% and specificities of 91-99% for CT in detecting appendicitis.[24] Studies in children have shown similar results, with sensitivities ranging from 95-100% and specificities from 93-100%, with an accuracy of between 94% and 99%. Interestingly, one of the smaller pediatric studies using CT without contrast had better sensitivity and specificity (both 100%) than the studies using IV, oral or rectal contrast, which showed sensitivities from 95-97% and specificities between 93% and 99% (with rectal contrast showing slightly better results than other contrast routes).[25]

The appendix should be examined for dilation and fat stranding, (*see Figure 12*) and an appendicolith may be present, occasionally even as an incidental finding.[4] (*See Figure 14.*) Once appendicitis has been diagnosed, it is often useful to determine if the appendix is perforated, to help guide therapy, including the possibility of nonsurgical treatment, and to calculate the likelihood of complications. Several signs have been identified that can indicate perforation on CT, with the most reliable predictor being extraluminal air (sensitivity 42.9%, specificity 96.9%). (*See Figure 15.*) Some signs, such as small-bowel dilatation (sensitivity

Figure 14. Acute Appendicitis



Appendicolith

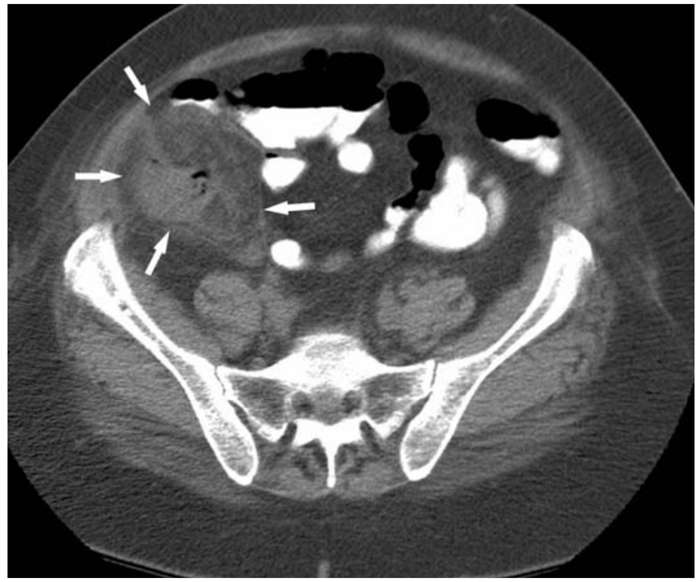
4.8%, specificity 95.4%) and abscess formation (sensitivity 9.5%, specificity 96.9%), are highly specific, but were observed in only a small number of patients in one study,[26] although other studies have shown higher sensitivities (34%, 53%) with similar specificities (99%, 93%) for abscess and ileus.[27] Other important signs include periappendiceal fluid collections (sensitivity 66.7%, specificity 73.8%), focal enhancement defects in the appendiceal wall (sensitivity 52.9%, specificity 55.4%), and either moderate or severe periappendiceal inflammatory stranding (sensitivity 76.2%, specificity 73.8%).[26]

Bowel Obstruction and Ischemia

Bowel obstruction and bowel ischemia are also issues pertinent to the emergency physician, and areas in which CT can be very helpful. In identifying bowel obstruction, CT is generally quite accurate, with sensitivities from 80-100%. Although peristalsis cannot be identified on CT, as it can on US, there are a few signs that are helpful in the recognition of obstruction, namely bowel caliber and the identification of a transitional zone. A small bowel caliber larger than 2.5 cm is deemed to be enlarged, and may indicate obstruction. (*See Insert Figure 16.*) In closed loop obstruction, several signs are regularly observed on CT, including C- or U-shaped loops of dilated bowel, adjacent collapsed loops, and "beak" or "whirl" signs. Adhesions, the most common cause of obstruction in the small bowel, can be identified as an enhancing band near the point of transition.[28]

Ischemia can be a result of obstruction, but it may also cause the obstruction in the first place. After ischemic injury, the bowel wall may appear hyper- or hypoattenuated on CT, and the degree of attenuation is diagnostically important. Other indirect signs, such as bowel wall thickening, localized fluid or hemorrhage, pneumatosis, and obscuration of the mesenteric vasculature, can also indicate ischemia.[28] CT detection of bowel ischemia has sensitivities and specificities of 79.2% and 98.5%, respectively, with positive predictive value (PPV) of 90.5% and negative predictive value (NPV) of 98.2%.[29]

Figure 15. Perforated Appendicitis



Note right lower quadrant phlegmon (arrows) containing fluid and bubbles of air.

Aorta

Of course, one of the first uses of CT angiography (CTA) in the abdomen was visualizing the aorta and its branches. The retroperitoneal vessels are readily apparent on NECT, CECT, and CTA, and these modalities can be used to assess for abdominal aortic aneurysm (AAA), mycotic aneurysm, and ruptured AAA, as well as stenoses or thromboses of the tributary arteries. During the workup of abdominal or back pain, a NECT and CECT of the abdomen may be ordered, and the aorta should always be evaluated. On CECT, it is possible to measure both the lumen diameter and the entire circumference of the aneurysm. (*See Insert Figures 17 and 18.*) In many cases, CECT is avoided in the suspected AAA rupture, secondary to the high mortality rate and the patients' poor condition, but if the rupture is an unsuspected finding, highly enhanced fluid can be visualized within the abdominal cavity in the proximity of the aorta.[19] Although sonography may detect AAA in asymptomatic patients, when a rupture is high on the differential, an NECT is the first choice for imaging. If hemorrhage is present, para-aortic fat streaking is a common finding, and fluid may be visualized in the retroperitoneum or the peritoneal cavity. (*See Insert Figures 17 and 18.*) When fluid is present in the abdominal space, the most likely cause is usually hemorrhage, and it is important to take note of the attenuation of the fluid, since this holds clues to the age of the bleed and the rate of hemorrhage. Isodense blood is generally fresh, indicating a rapid bleed and generally obviates emergency surgery. Fluid that appears as separate layers of differing attenuation may indicate a slower bleed as older, hyperdense layers of blood settle beneath the more recent, isodense strata.[2] Aortic dissection can be identified by the detection of an intimal flap on NECT. (*See Insert Figure 19.*) The distinction between the true and false lumen requires the use of intravascular contrast.

Bone

Finally, the bone window of the abdomen is an important consideration in the abdominal CT. Assessment of the lumbar spine and pelvis is similar to other bone windows in that the vertebrae and pelvic bones should be scanned for overt fractures or anomalies, and density should be analyzed for areas of decreased mineralization or abnormal ossification. Degenerative and lytic lesions should be noted, as well as symmetry and proper orientation.

Conclusion

The use of CT in the emergency department is increasing almost daily due to the increased availability of CT scans on an emergent basis and the increased quality of diagnostic imaging, especially with the recent advances in multislice CT. With the profusion of diagnostic imaging technologies in the emergency physician's arsenal, it is important to consider when to rely on options that involve less radiation exposure and less cost and when to opt for CT. For many renal indications, CT is the imaging modality of choice, especially if IVU or sonography is inconclusive. For urinary stones, CT has a sensitivity of 96-100% and specificity of 94-99%,[30] and for acute pyelonephritis (although usually diagnosed based on clinical symptoms, it can be confused with other disease processes and occasionally requires imaging), CT is much more sensitive than IVP.[31] Abdominal aortic aneurysms can be diagnosed initially by ultrasound, but free blood and abdominal branches are more accurately detected by CT.[32] In the gastrointestinal tract and biliary tree, the preferred study often varies by location and organ. For example, CT has a high sensitivity and specificity for detecting appendicitis,[24] good positive and negative predictive values for bowel ischemia,[29] and multislice CT has been shown to be the most dependable study to detect bowel perforation.[33] On the other hand, although CT can diagnose unexpected findings of gallstones or cholecystitis, ultrasound or hepatobiliary iminodiacetic acid (HIDA) cholescintigraphy are the preferred methods of evaluation when acute cholecystitis is suspected.[32] However, even while always taking into account radiation exposure risks and with precautions in children and pregnant patients (as mentioned above), for most abdominal indications, CT is the imaging modality of choice.

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Physician CME Questions

1. The American College of Obstetricians and Gynecologists' recommended limit for fetal radiation exposure (before significant adverse effects on the fetus) is:
   A. 3 rad.
   B. 4 rad.
   C. 5 rad.
   D. 6 rad.

2. A ventilation-perfusion (V/Q) scan results in significantly less fetal radiation exposure than a helical chest CT.
   A. True
   B. False

3. Thin-slice helical CT with colonic contrast can identify acute diverticulitis with a sensitivity of:
   A. 99%.
   B. 75%.
   C. 50%.
   D. 10%.

4. One of the best signs of ureteral calculi is the "rim sign." This indicates:
   A. rupture of the renal pelvis.
   B. inflammation of the ureteral wall.
   C. dilation of the bladder.
   D. obstruction of the urethra.

5. One small pediatric study without contrast had better sensitivity and specificity than studies using IV, oral, or rectal contrast.
   A. True
   B. False

6. Abdominal CT imaging for identification or exclusion of appendicitis is most useful in patients with:
   A. no clinical suspicion of appendicitis.
   B. an Alvarado score of 3 or less.
   C. an Alvarado score between 4 and 6.
   D. an Alvarado score greater than 7.

7. When renal and ureteral ultrasound is negative for calculi but there is strong clinical suspicion, the most reliable confirmatory imaging study is:
   A. noncontrast enhanced CT.
   B. intravenous urography (IVU).
   C. KUB.
   D. MRI.

8. Most data on radiation exposure risks come from:
   A. early studies by Benjamin Franklin.
   B. experiments by the Curies.
   C. large population studies of people exposed to medical imaging.
   D. retrospective analysis of survivors of Nagasaki and Hiroshima.

9. In adults, the lowest radiogenic dose significantly associated with increased risk of cancer is:
   A. 10 mSv.
   B. 50 mSv.
   C. 200 mSv.
   D. 500 mSv.

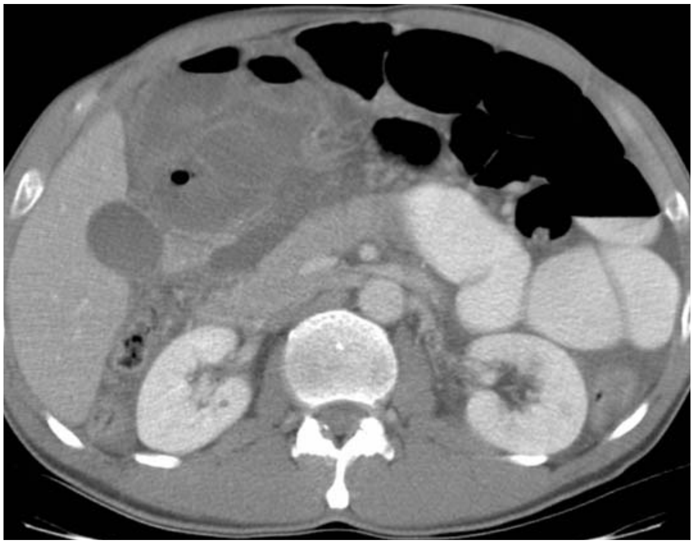
10. It is important to differentiate pancreatitis from signs of pancreatic malignancy. An abdominal CT that shows peripancreatic inflammatory changes of mesenteric fat, fluid collection around the pancreas, destruction of retropancreatic fat, and lymphadenopathy can generally exclude:
   A. pancreatic malignancy.
   B. diabetes mellitus.
   C. chronic pancreatitis.
   D. acute pancreatitis.

CME Answer Key

1. C; 2. B; 3. A; 4. B; 5. A; 6. C; 7. A; 8. D; 9. C; 10. D

In Future Issues: **Obstetrical Emergencies**

Figure 16. Small Bowel Obstruction

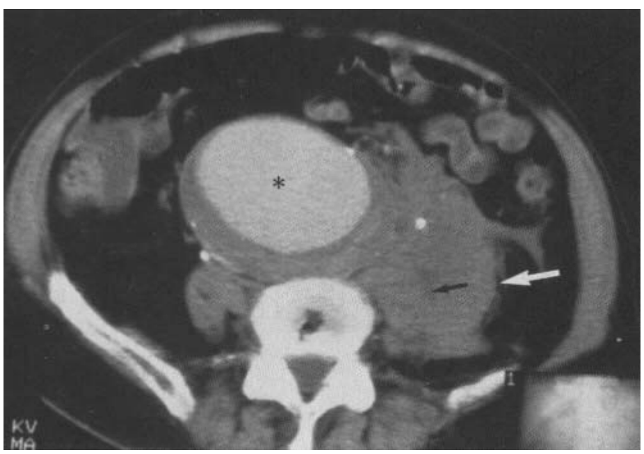


Multiple dilated loops of small bowel are filled with fluid and oral contrast material. The colon is collapsed.

Figure 17. Infrarenal Abdominal Aortic Aneurysm with Contained Retroperitoneal Leak

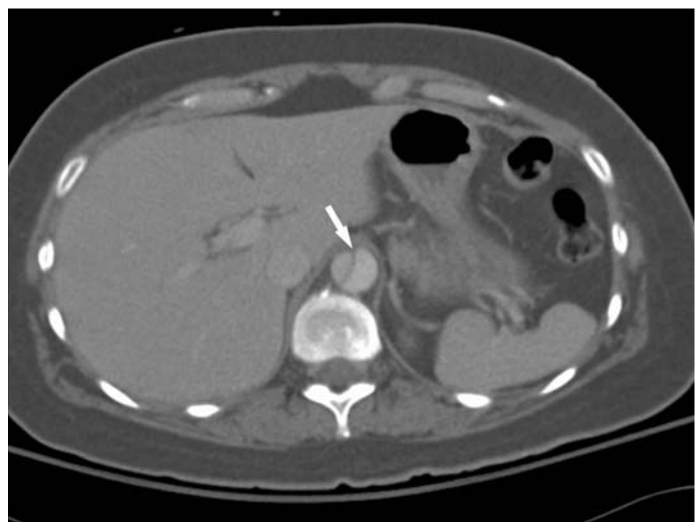
Note extensive anterior displacement of the left kidney, as well as mural thrombus within the aortic lumen.

Figure 18. Ruptured Abdominal Aortic Aneurysm



Note aortic lumen (asterix) and retroperitoneal hemorrhage (arrows).

Figure 19. Aortic Dissection



Note intimal flap separating the true and false lumens (arrow).

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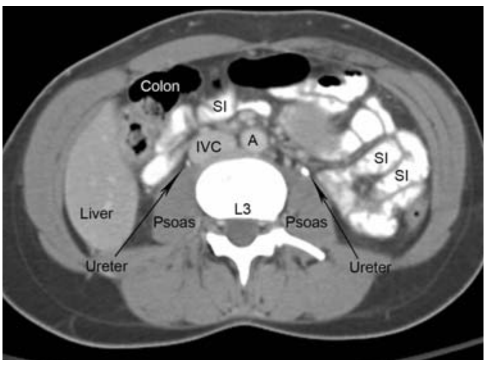
Normal Anatomy at the Level of the First Lumbar Vertebral Body (L1)

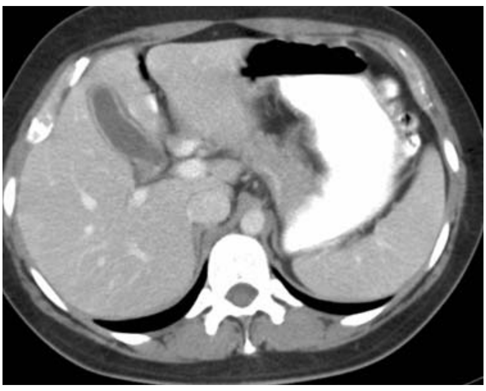
A; aorta, C; splenic flexure of colon, IVC; inferior vena cava, P; pancreas, PV; portal vein, RA; right adrenal gland, SMA; superior mesenteric artery, SI; small intestine, SV; splenic vein.

Normal Anatomy at the Level of the Third Lumbar Vertebral Body (L3)



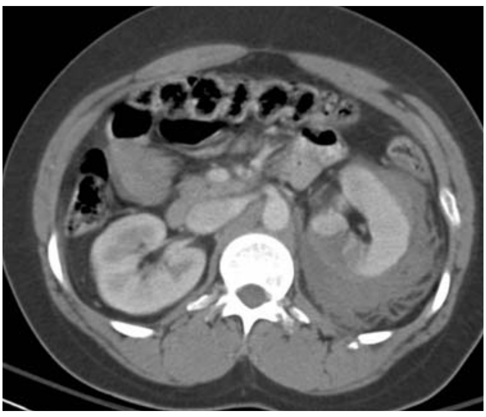
A; aorta, IVC; inferior vena cava, SI; small intestine.

Acute Cholecystitis



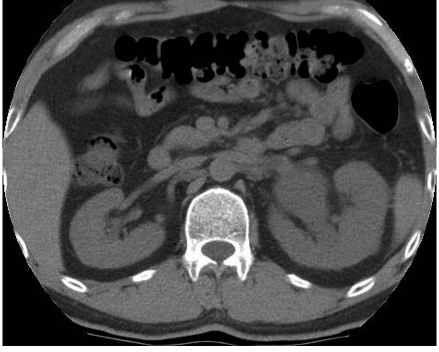
Note prominent gallbladder wall with pericholecystic fluid

Renal Injury Secondary to Blunt Abdominal Trauma

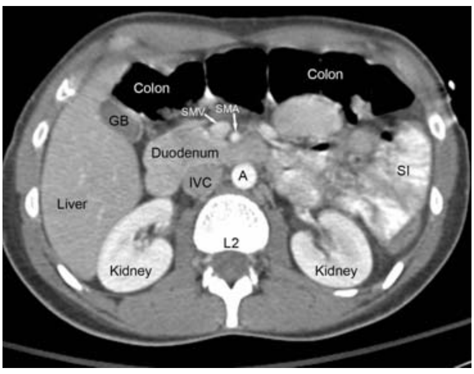


A moderate amount of perinephric hemorrhage is present.

Left Hydroureter



Normal Anatomy at the Level of the Second Lumbar Vertebral Body (L2)

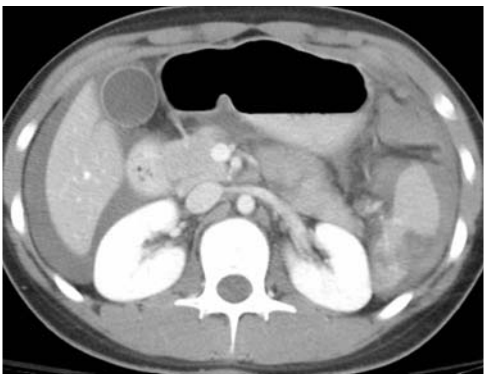


A; aorta, C; splenic flexure of colon, GB; gallbladder, IVC; inferior vena cava, SI; small intestine, SMA; superior mesenteric artery, SMV; superior mesenteric vein.

Liver Laceration Secondary to Blunt Abdominal Trauma

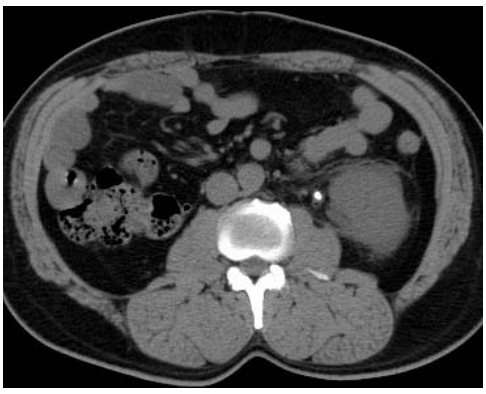
Note active extravasation of intravenous contrast (arrow). The absence of intraperitoneal fluid prevented diagnosis by focused assessment with sonography in trauma (FAST).

Splenic Laceration with Hemoperitoneum Secondary to Blunt Abdominal Trauma



Note free intraperitoneal blood surrounding both the spleen and liver.

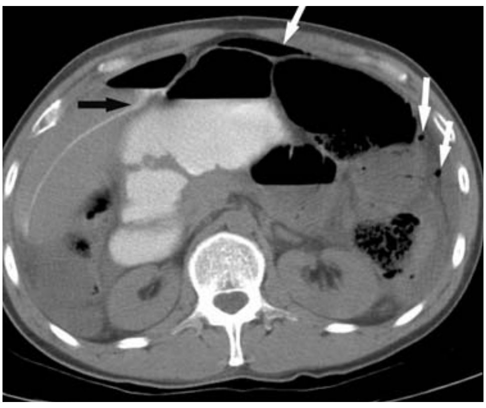
UPJ Stone



Renal stone located at the left ureteropelvic junction

Bladder Wall Calcification Due to Shistosomiasis

Duodenal Perforation



Duodenal perforation with free intraperitoneal air (white arrows) and extravasation of oral contrast material (black arrow).

Acute Appendicitis

White arrow shows enlarged appendix and periappendiceal fat stranding.

Perforated Appendicitis

Note right lower quadrant phlegmon (arrows) containing fluid and bubbles of air.

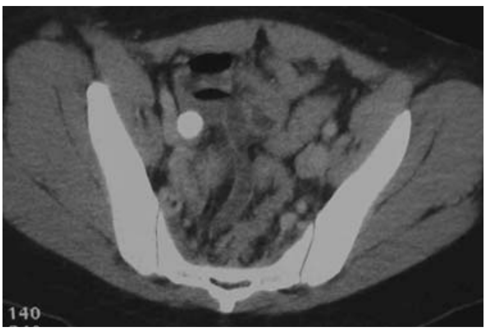
Infrarenal Abdominal Aortic Aneurysm with Contained Retroperitoneal Leak

Note extensive anterior displacement of the left kidney, as well as mural thrombus within the aortic lumen.

Jejunal Perforation Secondary to Blunt Abdominal Trauma

Note thickened jejunal loops (black arrows) and free intraperitoneal air (white arrow).

Acute Appendicitis

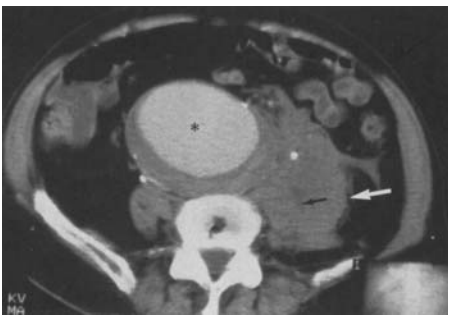


Appendicolith

Small Bowel Obstruction

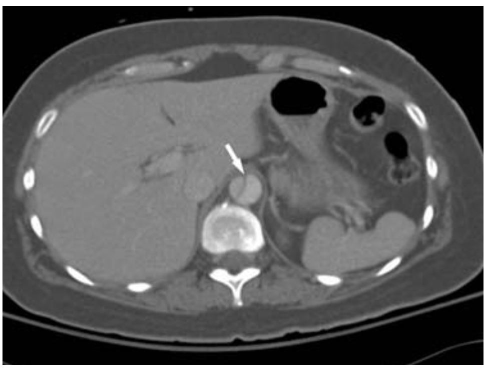
Multiple dilated loops of small bowel are filled with fluid and oral contrast material. The colon is collapsed.

Ruptured Abdominal Aortic Aneurysm



Note aortic lumen (asterix) and retroperitoneal hemorrhage (arrows).

Aortic Dissection



Note intimal flap separating the true and false lumens (arrow).

Supplement to *Emergency Medicine Reports*, January 1, 2008: "How to Read an Abdominal CT Scan." *Authors:* **J. Christian Fox, MD, RDMS**, Associate Professor of Emergency Medicine, University of California–Irvine School of Medicine, Irvine, CA; and **Jeffrey Westin, MD**, University of California–Irvine School of Medicine, Irvine, CA.
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Airway Management in the Pediatric Trauma Patient

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Traumatic injury remains the leading cause of death and a major cause of disability among children around the world.[1-3] Each year in the United States, there are more than 100,000 cases of traumatic brain injury (TBI) in children; 10%-15% are severe, resulting in permanent neurologic damage.[4]

Although TBI is the most common cause of death in childhood, many of these deaths may be preventable. Inadequate evaluation, resulting in inappropriate treatment, may contribute to approximately 30% of deaths in children with severe trauma.[5] Prompt, accurate assessment of the severity of injury and early initiation of appropriate critical care — including adequate oxygenation, ventilation and correction of hypotension — is of crucial importance in preventing these deaths. This article reviews the critical aspects of airway assessment and management in the pediatric trauma patient.

— The Editor

Issues in Infants and Children

Although the majority of children have structurally normal airways, normal changes occur with the child's physical maturation.[6] Additionally, among the children requiring emergency respiratory intervention, those with abnormal airways are overrepresented because of respiratory problems directly related to the structural abnormality, or their frequent association with other congenital anomalies.

Even the normal infant or child has several airway characteristics that increase the risk of airway obstruction and may make airway management challenging.

Anatomic Considerations of the Pediatric Airway. Many of the important anatomic and physiologic differences that exist between infants, children, and adults are either poorly understood or poorly appreciated (*Table 1*).[7] Ideally, respiratory compromise and failure should be anticipated rather than recognized so that

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appropriate measures can be taken before gas exchange is severely altered. Early, appropriate intervention will prevent the effects of hypoxemia and hypercarbia on the pediatric patient's central nervous and circulatory systems.

The Tongue. In newborns and infants up to about 2 years of age, the tongue lies entirely within the oral cavity. Unlike the adult, no portion of the tongue contributes to the upper anterior wall of the pharynx. Furthermore, in the infant, the tongue occupies a relatively large portion of the oral cavity (compared with the relatively smaller ratio of the adult tongue to the adult oral pharynx), which contributes to obstruction of airflow through the oral passageway.

When an obtunded child is difficult to ventilate, the tongue is the first site of potential obstruction to consider. Babies lying supine tend to flatten their tongues against the soft palate during inspiration. The tongue, especially if it is dry, stays against the soft palate during passive exhalation of air through the nose and is in a position to obstruct the next inspiration or positive-pressure breath and mask ventilation.

Nasal Passages. The nose of an infant is soft, distensible, and has relatively more mucosa and lymphoid tissue than the adult nose. The nares are angled forward, and the passageway through the turbinates to the posterior nasopharynx is more of a straight line back to the occiput. This is a helpful anatomic guide when attempting to pass a nasotracheal, nasopharyngeal airway, or nasogastric tube.

The nasal airway is the primary pathway for normal breathing in an infant.[7] During quiet breathing, resistance through the nasal passages is considerably greater than during mouth breathing. Despite the higher resistance, preferential or instinctive breathing through the nose is important for air warming, humidification, and particle filtration. Of note, total airway resistance and potentially compromised breathing is increased significantly in infants with nasal congestion, increased secretions, or by the presence of a nasogastric tube.

The Pharynx. The entrance to the pharynx is lined with rich lymphoid tissue (tonsils and adenoids). Hypertrophic adenoids may cause the normal nasal air conditioning mechanisms to be bypassed by causing partial or complete nasopharyngeal obstruction and forcing infants and children to breathe orally. Also, serious hemorrhaging from friable and inflamed adenoids can occur with placement of a nasal airway or nasogastric tube. Enlarged or hypertrophic tonsils may obstruct the entrance to the oropharynx.

The Larynx. In the newborn infant, the larynx is located at a level corresponding to the base of the occiput and C_1 to the superior border of C_4. This relatively high position of the larynx enables the epiglottis to pass up behind the soft palate and lock the larynx directly into the nasopharynx. This provides a direct air channel from the external nares through the nasal cavities, nasopharynx, larynx, and trachea to the lungs. Liquids can pass on either side of the interlocked larynx and nasopharynx into the esophagus. This anatomic configuration creates two separate pathways: a respiratory tract from the nose to the lungs and a digestive tract from the oral cavity to the esophagus. The separate respiratory and digestive routes prevent the mixing of ingested food and inhaled air. Hence, the newborn can breathe and swallow liquids simultaneously.[8,9] The connection between the epiglottis and the soft palate is constant, except for interruptions that occur during crying or with disease.

The combination of the large tongue, which is entirely within the oral cavity, and the high glottis makes it more difficult to establish a line of vision between the mouth and larynx during laryngoscopic examination. Because relatively more tissue is contained in less distance, the infant's larynx appears to be anterior and can make endotracheal intubation more difficult than in the adult.

Anatomic Transitions. Major position changes of the upper respiratory structures occur after the second year of life. The posterior third of the tongue descends into the neck and forms the upper anterior wall of the pharynx. The larynx begins a gradual descent to a lower position in the neck. By 7 years, the larynx lies between the upper border of the third cervical vertebrae (C_3) and the lower border of C_5 (from the tip of the epiglottis to the inferior border of the cricoid). By adulthood, the larynx descends farther and is located between the upper border of C_4 and the upper border of C_7. The lower position of the larynx in older children and adults results in a larger supralaryngeal portion of the pharynx. A true oropharynx is now apparent even during maximum elevation of the larynx. With the disappearance of the ability of the epiglottis to make contact with the soft palate, two separate pathways (i.e., one for air and one for liquids) no longer exist.

The larynx is the narrowest portion of the entire pediatric airway. The cricoid cartilage forms a complete ring, protecting the

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Table 1. The Pediatric Airway: Anatomic and Physiologic Differences

- Abundant secretions
- Greater dependence on nasopharyngeal patency
- Relatively larger tongue
- Relatively smaller oral cavity
- Size and security of teeth
- Relative and absolute size of tonsils and adenoids
- Floppier, more u-shaped or oblonged epiglottis[
- More acute angle between epiglottis and laryngeal opening
- More oblique inclination of the vocal cords
- Small caliber of glottis, trachea and airways
- Larynx higher in the neck
- Shorter neck
- Short trachea
- Small cricothyroid membrane
- Incomplete airway cartilage development
- Cricoid ring most narrow portion of the airway
- More prominent occiput
- Higher resistance to airflow
- Influence of sleep state on airway patency
- Enhanced bronchoconstriction

upper airway from compression. In the adult, the airway diameter of vocal cords and the trachea are of equal dimensions. If an endotracheal tube will pass comfortably through the vocal cords, it will equally traverse the cricoid cartilage. However, the newborn's laryngeal structures resemble a funnel — the narrowest portion of the airway is not the vocal cords, but the cricoid ring. An endotracheal tube that passes easily through the vocal cords may be tight within the cricoid ring, causing either temporary or permanent damage to the cricoid cartilage and potentially resulting in short- or long-term airway difficulties (e.g., subglottic stenosis).

Neck Position. Neck position plays a crucial role in airway obstruction. Because the infant has a large occiput, the head flexes forward onto the chest when the infant is lying supine with the head in the midline. In contrast, extreme neck extension also can obstruct the airway.[7] Midposition of the head with slight extension (the 'sniffing position') is preferred for airway maintenance. This is accomplished by placing a small pad under the shoulders to establish the best axis. Neutral cervical spine requirements (in the pediatric trauma patient) can be managed by this same airway positioning.[10]

The Pulmonary System. Compared with adults, the thoracic volume of a child is small and the airways are narrow and short. By virtue of the relatively small and short pediatric trachea, extubation or inadvertent endotracheal tube migration into either mainstem bronchus may occur during intubation. In addition, endotracheal tube movement readily occurs with changes in head position. Neck flexion displaces the tip of the endotracheal tube farther into the trachea, whereas extension of the neck moves the tube farther out of the trachea.[11]

There is a smaller amount of elastic and collagen tissue in the neonatal lung than in the adult lung. As a result, liquid or air can easily enter the pulmonary interstitium; this may explain the increased tendency of infants to develop pulmonary edema, pneumomediastinum, pneumothorax, and interstitial emphysema. Reduced elastic fibers contribute to the tendency for small airway collapse. Because elastic recoil of the thorax and lung is low, pleural pressure is nearly atmospheric and may contribute to airway closure.

The relative sizes of lung volumes and capacities remain the same throughout life. The tidal volume averages 6-7 mL/kg and constitutes approximately 8% of total lung capacity. Because the absolute tidal volume of the child is small, mechanical ventilators for children must be capable of providing small tidal volumes. Additionally, when infants receive manual or mechanical ventilatory support, the alveoli served by the peripheral airways require time to fill and empty. Inspiratory time must be adequate for chest expansion and alveolar ventilation, and expiratory time must be adequate to allow alveoli to empty. If alveoli do not empty completely prior to the next breath, they become overdistended, and complications, such as alveolar rupture or pneumothorax, may occur.

Chest Wall Mechanics. The chest wall encloses and supports the lungs. The cartilaginous ribs of the infant and young child are twice as compliant as the bony ribs of the older child or adult. During respiratory distress, the infant's chest wall retracts and, thereby, reduces the ability to maintain functional residual capacity, prevents increases in tidal volume, and increases the work of breathing.

Because of their soft, compliant chest walls, newborns and infants tend to have a low relaxation lung volume. However, they are capable of maintaining functional residual capacity above this low relaxation volume by various mechanisms directed at breaking expiratory flow (e.g., grunting). Unfortunately, these mechanisms may not be effective when lung compliance is reduced (e.g., pulmonary contusion), when neurologic control is impaired (e.g., trauma, drug effects), or when the infant's trachea is intubated.[7] Under these circumstances, the functional residual capacity may decrease to volumes incompatible with alveolar stability, resulting in alveolar closure, atelectasis, and hypoxemia. Furthermore, because children have compliant chest walls, health care providers must use caution when restraining children to backboards for spinal immobilization. Excessive restraints may impair chest wall movement.[12] As the child grows, chest wall compliance decreases and elastic outward recoil of the rib cage increases because of an increase in chest wall muscle tone. These changes improve the child's ability to maintain functional residual capacity, reducing the likelihood of atelectasis and small airway closure.

In infants, the ribs are oriented in a more horizontal direction than in adults and they articulate with both the spinal column and sternum. The infant's chest has less anterior-posterior displacement during inspiration than the adult chest. Intercostal muscles lack the leverage needed to lift the ribs and expand the chest effectively. These factors tend to reduce the mechanical efficiency of respiratory muscle function during the first years of life. As the child grows, the rib articulation changes to a 45° downward angle and the intercostal muscles are able to elevate the ribs and contribute to chest expansion. Consequently, the intercostal muscles relative to the ribs are not maximally efficient and effective in young infants; they act primarily to stabilize the ribs and chest wall during the first years of life.

The Diaphragm. In the newborn, the diaphragm is nearly horizontal, whereas in adults, insertion is oblique. Horizontal insertion of the diaphragm tends to draw the lower ribs inward during spontaneous respiration. This diaphragmatic work is wasted since the resulting chest wall distortion does not improve ventilation. The tendency to draw the ribs inward is exaggerated in the supine position. Because oblique insertion expands the chest, the efficiency of diaphragmatic contraction increases with growth. Moreover, any compromise of diaphragmatic excursion (e.g., gastric distention) can predispose the child to the development of respiratory failure. Therefore, it is important to prevent abdominal distention in the child.

Endotracheal Tube Size. Even selecting an endotracheal (ET) tube of the correct size is less straightforward in children than in adults. The formula (internal diameter = age(years)/4 + 4) is the best approximation for children older than 2 years, while published guidelines work best for younger infants. A tube with its diameter equal to the width of the child's fifth fingernail is likely to be appropriate. In most cases there should be a leak around the tube at 20-30 cm H_2O.[6] Multiple studies have indicated that the absence of a leak at less than 30-40 cm H_2O is highly predictive of postextubation upper airway obstruction.[13,14]

Because the narrowest portion of the child's airway is at the cricoid (rather than at the vocal cords, as in adults), uncuffed tubes commonly provide an adequate fit with minimal loss of delivered tidal volume. Traditional recommendations have been to use uncuffed endotracheal tubes in children younger than 8 years. However, in an attempt to avoid intubating children with inappropriately large tubes, physicians often select a tube that is so small and has such a large leak around it that effective ventilation is impossible. Recent evidence shows that cuffed tubes can be used safely in younger children, and may actually decrease the risk of complications, at least in the short term.[15] Khine and colleagues recommend using the following formula for a cuffed tube:

internal diameter = age [years]/4 + 3

using an upward rounding approach to age (e.g., a child who has passed his first birthday is considered to be 2 years old).[16] In the operating room, tube selection by this formula is appropriate in 99% of patients.

Appropriate depth of placement is also important. Most of the available recommendations lead to inappropriate tube placement in many patients. Excessively low placement often is associated with mainstem bronchial intubation, atelectasis, pneumothorax, and severe hypoxemia. A tube placed too high is more likely to be dislodged. One suggestion for correct placement is to multiply the endotracheal tube diameter by 3 to determine appropriate depth. Using the diameter chosen according to the age-based formula ([age/4] + 4) results in inappropriate placement in more than 40% of patients.[17] One of the simplest and best suggestions to date is to use a tube with markings along its entire length, and place the 3.0-cm mark at the cords for all infants requiring a 3.0-3.5 internal diameter tube, at 4.0 cm for those with 4.0-4.5 tubes, and at 5.0 cm for those with 5.0-5.5 tubes.[18] Obtaining a chest x-ray soon after intubation, with the child's head in neutral position, is strongly recommended. Once the tube is in good position, noting and recording its depth and making sure that all subsequent x-rays are taken in the same neutral position minimizes further need for x-rays (and the associated exposure and cost).

Even with the tube in good position, right upper lobe atelectasis is common in infants and young children. While pooling of secretions and debris in a small, posteriorly angled bronchus is often the cause, a recent report notes that persistent right upper lobe atelectasis in children can be associated with a tracheal bronchus, a variation occurring in approximately 2% of the population.[19] While this would rarely be a problem in a larger patient, the length of trachea available for ET tube placement in a small child is sufficiently short that the potential to occlude the bronchial orifice is substantial.

The Trauma Patient: Initial Assessment and Management

In the initial stabilization of all trauma patients, including head-injured children, control of the airway and adequate ventilation are the first priorities. In TBI, it is particularly important to maintain oxygenation and prevent hypoxemia, since even moderate reductions in PaO_2 levels can contribute to secondary neural injury in the injured brain. The traumatically injured brain is particularly susceptible to secondary insults such as hypoxia-ischemia. In addition, even moderate hypoxia (PaO_2 level less than 40-50 mmHg), which might not reach a level that affects cerebral viability, is a potent vasodilator and may contribute to cerebral swelling. It is also important to maintain normocarbia, since even moderate hypercarbia can cause arteriolar vasodilation and increased cerebral blood volume, which could further contribute to increased intracranial pressure and precipitate herniation. Hypercarbia (and hypoxemia) may have several causes in head-injured patients, especially in the field, where poor airway control and respiratory failure are common. Hypercarbia has been found in 15%-20% of head-injured patients and can be prevented by intubation and ventilation.[20]

Bag-valve-mask Ventilation. Airway management in children is a difficult task. The anatomic and physiologic differences in children must be kept in mind when approaching the patient. Remember that the single most common cause of respiratory deterioration in infants and children is an inadequate airway.

The sniffing position is accomplished by placing the child on a hard surface and rotating the head back so that the child's face is directed upward. In the case of the trauma victim, this maneuver must be performed with in-line stabilization to protect a potentially unstable cervical spine from further injury. In the trauma victim, the head should not be forcefully rotated. In this situation, gentle in-line stabilization in the neutral position is used, and further manipulation is restricted to the jaw-thrust or chin-lift maneuvers or insertion of an oral or endotracheal airway.

Despite proper positioning of the head, decreased tone in the muscles protecting the upper airway or a foreign body in the airway still may produce obstruction. The first problem can be relieved by the jaw-thrust or normal chin-lift maneuvers, the insertion of the oral airway, or the insertion of an endotracheal tube. The jaw-thrust maneuver is performed by placing a finger behind the angle of the mandible on each side and exerting anterior pressure to life the jaw. The chin lift maneuver is performed by placing a finger under the chin and lifting. Both of these maneuvers displace the mandible anteriorly and separate the tongue from the posterior pharyngeal wall.

Opening the airway also can be accomplished by inserting an oral pharyngeal airway. An oral airway is 'sized' by placing it next to the child's cheek. The end of the oral airway should just touch the angle of the mandible. An oral airway that is too small can be swallowed, and one that is too large can traumatize the posterior pharynx or come to rest in the laryngeal vestibule, thus creating even more upper airway obstruction and defeating its own purpose. An oral airway should only be placed in a child after the child's airway has been visually inspected for a foreign body. Otherwise, there is risk that the oral airway may push a foreign body deeper into the child's airway, making removal more difficult. Oral airways are poorly tolerated by most conscious patients. When an oropharyngeal airway is introduced into a conscious or stuporous patient— especially in an infant or child — laryngospasm or vomiting may be induced. Care should be taken in its placement because incorrect insertion usually displaces the tongue backward into the pharynx and can result in or worsen airway obstruction.

In addition to the above maneuvers to open the airway, constant attention to nasopharyngeal and oral suctioning is necessary to remove secretions that can compromise airway patency. Because neonates are obligate nosebreathers with small nasopharynxes, even a small amount of secretions can cause major obstruction, as can a nasogastric tube.

Frequently, opening the airway is all that the patient needs to breathe effectively. If the patient does not spontaneously breathe when the patency of the airway is established, ventilation is necessary.

The use of the bag-valve device and mask has several advantages: It provides an immediate means of ventilatory support; it conveys a sense of compliance of the patient's lungs to the rescuer; it can be used with spontaneously breathing patients; and it can deliver an oxygen-enriched mixture to the patient.

Typically, the bag-valve device is available in three sizes: adult, child, and infant. Studies show that standardized adult and pediatric bag-valve devices provide equally effective ventilation in an infant mannequin lung model. Also, the use of larger resuscitation bags did not result in excessive ventilation.

Small-volume (infant) self-inflating bag devices do not deliver an adequate tidal volume to the infant with poorly compliant lungs. The small bag volumes also limit the duration of inspiration, which needs to be prolonged when the lungs are atelectatic. Thus, child-size and adult-size self-inflating bags may be utilized for the entire range of infants and children.

Although its use has gained widespread acceptance in all care settings, the bag-valve-mask device also has been characterized as cumbersome and difficult to use. The most frequent problem with the bag-valve-mask device is the inability to provide adequate ventilatory volumes to a patient who is not endotracheally intubated. This most commonly results from the difficulty of providing a leak proof seal to the face while maintaining an open airway. It also occurs when the bag is not squeezed sufficiently enough to force an adequate amount of air into the patient's lungs.

Optimizing bag ventilation during cardiopulmonary resuscitation or ventilation of an unprotected airway is mandatory to minimize the risk of pulmonary complications and the occurrence of gastric inflation due to excessive airway pressure.[21,22] Numerous studies have underlined the difficulty of providing safe and effective bag ventilation in these situations.[21,22]

Good bag-valve-mask ventilation technique is mandatory because the child must be kept alive while preparations are made for a safe and controlled intubation. This is not a basic life support skill as much as an initial life support skill.

Endotracheal Intubation. Endotracheal intubation is often accomplished after the airway has been secured and the patient has been adequately ventilated with a bag-valve-mask device to ensure oxygenation and removal of carbon dioxide.

The decision to intubate and begin ventilatory assistance is always a clinical one; arterial blood gas values are at best a helpful guide. Early elective intubation is often wise, even if progressive CO_2 retention does not occur, or if hypoxemia is corrected but with high concentrations of supplemental oxygen.

Pitfalls in intubation include lack of experience in intubating children, selection of the incorrect route for intubation, failure to preoxygenate, improper use of the laryngoscope, forcing the tracheal tube into the airway, passing the tube too far or not far enough, prolonged attempts to intubate, and equipment malfunction or unavailability.

When used by properly trained providers, ventilation via a tracheal tube is the most effective and reliable method of assisted ventilation. (*See Tables 2 and 3.*)

Identify the Difficult Airway Prior to the Intubation Procedure. Expert performance of endotracheal intubation can be life-saving, while inability to perform this technique adequately can be life-threatening. Identification of potential problems, pre-intubation anatomic evaluation, equipment and drug preparation, and anticipation of potential complications will allow for a high success rate. Furthermore, physicians must have a logical, safe, alternate plan for airway management when faced with a patient who is difficult to intubate or who cannot be ventilated.

If time allows, a pre-intervention history and physical examination will identify most patients who will be difficult to intubate. The American Society of Anesthesiologists risk classification system will identify patients at highest risk for adverse outcome from administration of general anesthetics, paralysis, and endotracheal intubation (*Table 4*).[23]

Table 2. Endotracheal Intubation: Advantages and Indications

ADVANTAGES OF ENDOTRACHEAL INTUBATION:

- The airway is isolated to ensure adequate ventilation and delivery of oxygen without inflating the stomach.
- The risk of pulmonary aspiration of gastric contents is minimized.
- Inspiratory time and peak inspiratory pressures can be controlled.
- Secretions and other debris can be suctioned from the airways.
- Positive end-expiratory pressure can be delivered.

INDICATIONS FOR ENDOTRACHEAL INTUBATION INCLUDE:

- Inadequate central nervous system control of ventilation resulting in apnea or inadequate respiratory effort
- Functional or anatomic airway obstruction
- Excessive work of breathing leading to fatigue
- Need for high peak inspiratory pressures or positive end-expiratory pressures to maintain effective alveolar gas exchange
- Lack of airway protective reflexes
- Permitting paralysis or sedation for diagnostic studies while ensuring protection of the airway and control of ventilation

Table 3. Intubation Equipment

BEFORE ATTEMPTING INTUBATION, ASSEMBLE THE FOLLOWING EQUIPMENT:

- A tonsil-tipped suction device or a large-bore suction catheter
- A suction catheter of appropriate size to fit in the tracheal tube
- A properly functioning manual resuscitator, oxygen source, and a face mask of appropriate size
- A stylet to provide rigidity to the tracheal tube and help guide it through and beyond the vocal cords. If a stylet is used, it is important to place the stylet tip 1 to 2 cm proximal to the distal end of the tracheal tube to prevent trauma to the trachea from the stylet.
- Three tracheal tubes, 1 tube of the estimated required size and tubes 0.5 mm smaller and 0.5 mm larger
- A laryngoscope blade and handle with a functioning bright light (and spare bulb and batteries if possible)
- An exhaled CO_2 detector (capnography or colorimetric)
- Tape to secure the tube and gauze to dry the face. An adhesive solution also may be used on the tube and face, or a tracheal tube holder may be considered.

Direct examination of the airway can identify patients who will be at greatest risk for difficult intubation and inability to ventilate. A few simple measurements can be useful and include the mental-hyoid distance and the upper-lower incisor distance. The upper-lower incisor distance with open mouth should be assessed in infants and children. A quick look into the posterior pharynx (without any instruments) will reveal either evidence of a difficult airway (e.g., a large tongue, blood, swelling, or secretions) or an easier airway with visible faucial pillars, soft palate, and uvula. While a short neck, small mandible, large tongue, obesity, high arched palate, scoliosis, and limited mandible or cervical spine mobility account for a significant number of difficult airway cases, some patients who appear normal to conventional examination still may present an unanticipated airway problem. (*See Tables 5 and 6.*)[24]

Prior to endotracheal intubation, clinicians must have a plan of action for dealing with difficult or failed attempts at intubation. Always prepare rescue equipment in advance whether or not difficulties are anticipated. If patients have anatomic obstruction (e.g., fractured larynx) or maxillofacial trauma, equipment, and personnel (e.g., surgeon and anesthesiologist) should be readied in case surgical airway techniques are necessary.

Predictable consequences or risks attend laryngoscopy and intubation (*Table 7*). Efforts must be made to minimize these problems.

The Intubation Procedure. In a child with a perfusing rhythm, endotracheal intubation should always be preceded by the administration of supplemental oxygen. Assist ventilation only if the patient's effort is inadequate. If a rapid sequence intubation (RSI) procedure is anticipated (*See Rapid Sequence Intubation section on page 7*), avoid assisted ventilation, if possible, because it often inflates the stomach and increases the risk of vomiting and aspiration. If trauma to the head and neck or multiple trauma is present, the cervical spine should be immobilized during intubation.

Because morbidity can occur from an improperly placed tracheal tube or from hypoxia created during prolonged intubation attempts, attempts should not exceed approximately 30 seconds, and the heart rate and pulse oximetry should be monitored continuously.

Intubation is probably best performed by the most skilled provider present. In a child in cardiac arrest, do not delay intubation to apply a device to continuously monitor the rhythm. Furthermore, pulse oximetry will not function if the patient does not have detectable pulsatile perfusion.

Either a straight or a curved laryngoscope blade may be used. When a straight blade (preferred blade in infants and children) is used, the blade tip is usually passed over the epiglottis to rest above the glottic opening. Use the blade traction to lift the base of the tongue and directly elevate the epiglottis anteriorly, exposing the glottis. When using a curved blade, insert the tip of the blade into the vallecula (the space between the base of the tongue and the epiglottis) to displace the base of the tongue anteriorly. Do not use the laryngoscope blade and handle in a prying or levering motion, and do not place pressure directly on the teeth, lips, or gums.

The appropriate depth of insertion of a tracheal tube can be estimated from the following formula:

Depth of insertion (cm) = internal tube diameter (in mm) $\cdot$ 3.

An alternative formula to estimate appropriate depth of insertion in children older than 2 years is:

Depth of insertion (cm) = (age in years/2) +12.

Verification of Proper Tube Placement. Once the tracheal tube is positioned, provide positive-pressure ventilation, observe

Table 4. American Society of Anesthesiologists (ASA) Risk Classification

ASA CLASS
I. Patient normally health
II. Mild to moderate systemic disease
III. Severe systemic disease
IV. Severe systemic disease – constant threat to life
V. Moribund – not expected to survive

Table 5. Anatomic Indicators of Difficult Airway

- Large tongue or inability to see soft palate, uvula, or faucial pillars
- Limited distance between upper and lower incisors
- Limited hinge movement of TMJ (e.g., trismus from deep space infection, maxillofacial trauma)
- Micrognathia
- Cervical spine abnormalities
- High-arched palate
- Macroglossia or glossoptosis
- The morbidly obese patient
- Upper airway obstruction, bleeding, trauma, burn, inhalational injury, craniofacial abnormality

Key:
TMJ = temporomandibular joint

chest wall movement, and listen for breath sounds over the peripheral lung fields. If the tube is properly positioned, there should be symmetrical, bilateral chest rise during positive-pressure ventilation, and breath sounds should be easily auscultated over both lung fields, especially in the axillary areas. Breath sounds should be absent over the upper abdomen. The presence of water vapor in the tube is not a reliable indicator of proper tracheal tube position. Tracheal tube placement should be confirmed by monitoring exhaled CO_2 levels, especially in children with a perfusing rhythm.

Securing the Endotracheal Tube. Once intubated, the ET tube then needs to be secured with tape so that displacement does not occur with movement. Taping the tube is a two-person job!

Although there are several methods of effective taping, always be sure that the head and the tube move as a unit and that kinking and angular bends of the tube are not possible. Stabilization to prevent rotation, flexion, or extension of neck is necessary before patient movement. Flexion and extension of the head may displace the tube either into a mainstem bronchus or up into the pharynx, with potential catastrophic consequences.[25]

After the tube is taped into place, confirm its position within the trachea clinically and by chest x-ray because transmitted breath sounds may be heard over the left hemithorax despite a right main bronchus intubation. In addition, the chest x-ray helps to identify and correct the position of a tube located high in the trachea, which is at high risk of displacement during movement.

Always measure and record the depth of the ET tube at the lip or the child's incisors. After any patient movement or changes in clinical status, confirm that the depth of the ET tube has not changed.

Once the ET tube is placed and secured, constant cardiopulmonary monitoring is essential. If an intubated child begins to deteriorate, consider the following possible complications:

- displacement of the endotracheal tube into the right mainstem bronchus, pharynx, or esophagus;
- ET tube obstruction with saliva, mucus, blood, foreign body, or purulent secretions;
- mechanical failure involving the bag-valve device or the ventilator; or
- pneumothorax

Rapid Sequence Intubation. Rapid sequence intubation (RSI) was developed as a means of handling the airway of a decompensating patient in the ED. It should be differentiated from rapid sequence *induction*, which is the classic anesthesia term used to describe the induction of anesthesia.[26] RSI is now a standard part of training in emergency medicine residencies and is increasingly taught in pediatric resuscitation courses.[27-31]

The goal of RSI is to take a patient from his/her starting level of consciousness to an unconscious, neuromuscularly blocked state and perform tracheal intubation without intervening positive-pressure ventilation. Because most ED patients are not fasting, patients are at increased risk of aspiration if positive-pressure ventilation is performed before airway control and air is allowed to enter the stomach. In most situations, correctly performed RSI allows a clinician to manage a patient's airway without positive-pressure ventilation until the ET tube is secured in the patient's trachea. RSI also increases the chance of successful placement of the ET tube through relaxation of the patient's musculature by neuromuscular blockade and gives the clinician the ability to manage the physiologic response of the body to laryngoscopy by the addition of various pharmacologic agents.

Medications used in RSI typically can be divided into two categories: *induction agents* and *neuromuscular blocking agents*. The induction agents fall into many classifications, but all serve to sedate the patient to intubate. The most commonly used induction agents are the benzodiazepines (e.g., midazolam, lorazepam, and diazepam), thiopental, ketamine, etomidate, and the opioids. Each has its advantages and disadvantages in specific clinical scenarios. All are given after the patient is preoxygenated but before any neuromuscular blockers are administered. The clinician must be familiar with the indications and common side effects of these medications and know when a situation calls for a specific agent. Clinical scenarios to remember are the hypotensive patient and the patient with raised intracranial pressure.

The benzodiazepines are sedative/hypnotic drugs often used in clinical practice to control seizure activity. They are efficient sedatives and amnestic agents but do not provide any pain control. Their rate of onset depends upon the agent, but midazolam (Versed®) has the quickest onset and shortest duration of the group. Midazolam (Versed®; 0.1 to 0.2 mg/kg IV) is extremely versatile and can be given via oral, intravenous, intramuscular, subcutaneous, and intranasal routes. The most common side effects with benzodiazepines are respiratory depression — most

Table 6. Potential Indications of a Difficult Intubation

ANATOMIC ABNORMALITIES
Short neck
Receding mandible
Narrowed mouth with high arched palate
Limited movement of mandible
Maxillary protrusion
Cervical rigidity
Obesity
CONGENITAL ABNORMALITIES
Choanal atresia
Encephalocele involving nasofrontal region
Macroglossia
Treacher-Collins syndrome
Craniofacial dysotosis (Crouzon's syndrome)
Klippel-Feil syndrome
Achondroplasia
Subglottic cysts
Cystic hygroma
Vascular compression of trachea
Subglottic stenosis
Mucopolysaccharide disease
Laryngeal web
Down syndrome
TRAUMA
Facial injuries
Mandibular fractures
Maxillary fractures
Laryngeal and tracheal trauma
Hemorrhage into respiratory tract
Tracheal rupture
Cervical spine injury
INFLAMMATORY
Rheumatoid arthritis
Cervical fixation
Temporomandibular disease
Cricoarytenoid disorders
Ankylosing spondylitis
TUMOR MASS
Cystic hygroma
Hemangioma

Table 7. Complications of Laryngoscopy and Intubation

- Tachyarrhythmias and bradyarrhythmias
- Impedance to systemic and jugular venous return
- Hypertension or hypotension
- Hypoxia
- Hypercarbia
- Increased intracranial, intragastric, and intraocular pressures
- Injury to airway structures (from lips or nose to alveoli)
- Regurgitation or vomiting with possible aspiration
- Inadvertent placement of the tube into the esophagus, soft tissues, or cranial vault
- Cervical spinal cord injury
- Generation of significant pain and anxiety

often seen with diazepam — and hypotension. The patient should be observed for a fall in blood pressure. For this reason, the benzodiazepines should be used with caution in patients with severe cardiovascular compromise, such as those with multiple trauma.

Thiopental (Pentothal®; 2 to 5 mg/kg IV) is a barbiturate that has been commonly used as an induction agent in RSI. It also can cause hypotension but is a very useful agent in patients with increased intracranial pressure. It is the drug of choice in normotensive patients with isolated head injuries or raised intracranial pressures. It produces significant cardiovascular depression and should be avoided in patients with volume depletion or hypotension.

Ketamine (Ketalar®; 1 to 2 mg/kg IV over 1 to 2 minutes) is a dissociative amnestic agent similar to the street-drug phencyclidine. It induces a 'dissociative amnesia' in patients, which is described as a sensation in which the mind is 'separated' from the body. Ketamine increases the release of catecholamines, which helps thwart the usual bradycardia commonly seen in pediatric patients when the insertion of a laryngoscope causes vagal stimulation and helps to dilate the small airways through beta-2 receptor activation. Ketamine is very useful in patients with status asthmaticus but should not be used in patients at risk for increased intracranial pressure as it tends to increase intracranial pressure secondary to the adrenergic surge.

Etomidate (Amidate®; 0.2 to 0.3 mg/kg IV) is a more recent addition to the RSI armamentarium and is classified as an imidazole hypnotic agent. The benefit of using etomidate is that it does not cause either hypotension or an increase in intracranial pressure. This useful characteristic makes etomidate an ideal drug for the multi-trauma patient at risk for closed head injury and hypotension, and these favorable hemodynamic benefits seem to extend even to young children.[32,33] Care must be taken, however, when using this drug in patients with adrenal suppression, as etomidate can cause further adrenal suppression by directly inhibiting the conversion of cortisol from 11-deoxycortisol in the adrenal gland. This phenomenon has been documented even after a single dose of etomidate.[34,35]

Narcotics such as fentanyl and morphine have been used in the past for induction, but large doses are required to have significant sedative effects. They are sometimes combined with benzodiazepines. This combination causes a drop in systemic vascular resistance and, therefore, should be avoided in patients with cardiovascular compromise. For this reason, the other agents previously mentioned are preferred in the setting of RSI.

The paralytic agents can be divided into *depolarizing* and *nondepolarizing agents*. All work at the neuromuscular junction to paralyze the muscle. Succinylcholine (Anectine®, Quelicin; 1.0 to 1.5 mg/kg IV) is the classic depolarizing agent and works to bind to the neuromuscular receptor and depolarize the fiber to render it immune to further stimulation. Its strengths are its quick onset (approximately 30 to 60 seconds) and short duration (5 to 10 minutes). It has been shown to induce a rise in potassium of approximately 0.5 to 1.0 mEq/L[26] and cause a slight increase in intracranial pressure as well as slightly increase airway secretions. It should, therefore, be used with caution in any patient at risk for hyperkalemia as succinylcholine-induced arrhythmias are well documented.[27] It should be avoided in patients with a history of renal failure, paralysis, a significant burn older than 48 hours, or those confined to bed. Because an undiagnosed myopathy (e.g., muscular dystrophy) may lead to hyperkalemia and cardiac arrest, some authorities recommend avoiding succinylcholine in pediatric patients, especially males.[26]

The rise of intracranial pressure by succinylcholine can be blunted by pretreatment of the patient with lidocaine (Xylocaine; 1.5 mg/kg IV) 3 minutes before the succinylcholine is administered. Lidocaine should be strongly considered in the management of patients at risk for increased intracranial pressures, although the exact mechanism by which the drug attenuates a rise in intracranial pressure is not definitely established.[36]

Atropine (0.02 mg/kg IV; minimum dose 0.1 mg; maximum single dose of 0.5 mg for a child and 1.0 mg for an adolescent) should be given to all patients younger than 5 years before inducing neuromuscular blockade to block the bradycardia secondary to vagal stimulation by laryngoscope blade insertion. However, it must be recognized that pretreatment with atropine does not prevent bradycardia in all cases.[37] Atropine also blocks the increased secretions caused by succinylcholine and ketamine.

Pancuronium (Pavulon®; 0.1 mg/kg IV), rocuronium (Zemuron®; 0.6 to 1.0 mg/kg IV), and vecuronium (Norcuron®; 0.15 mg/kg IV) are the most commonly used nondepolarizing agents and bind to the neuromuscular receptor causing blockade but no depolarization. All act less quickly and last much longer than succinylcholine. Of these drugs, rocuronium has the fastest onset of action (60 to 90 seconds) with a duration of action of approximately 30 to 45 minutes. Pancuronium has the slowest onset and longest duration of action lasting up to 60 to 90 minutes. Mivacurium (0.2 to 0.3 mg/kg IV), another nondepolarizing agent, also can be used in RSI. While this drug has an onset of action similar to the other nondepolarizers, its duration of action is only twice as long as succinylcholine.[26] Mivacurium causes histamine release and may cause hypotension, but this side effect seems to be attenuated when the medication is given slowly over 30 seconds or more.[26]

There is no risk of raising potassium levels or intracranial pressure with these nondepolarizing agents, making them ideal when succinylcholine is contraindicated. Due to their long duration of action, though, it is essential to have a secondary means of oxygenating and ventilating the patient close at hand in case the ET tube cannot be placed. In patients who are difficult to ventilate with a bag-valve mask, a laryngeal mask airway (LMA) may be helpful to oxygenate and ventilate before repeat laryngoscopy.[38]

There is evidence that RSI is safe and effective in pediatric patients.[30,31,39-41] RSI is associated with a higher success rate of intubation and a lower complication rate. Importantly, intubation without premedication may worsen outcomes for unconscious patients with intracranial hemorrhage.[42]

Alternative Airway Devices. In the absence of personnel trained in tracheal intubation, or if attempts at tracheal intubation fail, there are alternative airway devices that may be better than an oropharyngeal airway and bag-valve device.

The laryngeal mask airway (LMA) allows rapid, effective ventilation with a single operator, with improved oxygenation, less hand fatigue, and less risk of gastric inflation compared with ventilation with a facemask.[43-46] Training in use of the LMA is quicker and easier than for tracheal intubation, although the number of insertions required to achieve and maintain sufficient skill has not been defined.[44]

Currently PALS does not recommend the use of LMAs in children as a result of limited data comparing their use with ET intubation and BVM ventilation in the resuscitation of children; nonetheless, they are used widely in operating room settings, emergency departments, and by some prehospital care systems.[29,47]

Controlled Ventilation. The use of controlled ventilation has long been a modality for the treatment of intracranial hypertension and is based on the known cerebrovascular response to changes in $PaCO_2$. The relative change in cerebral blood flow (CBF) during variations of $PaCO_2$ levels depends upon several factors including baseline CBF, cerebral perfusion pressure, and anesthetic drugs.[48] However, in a wide variety of subjects and conditions, most studies report a change in global CBF of 1-2 mL/100 g/min for each 1 mmHg change in $PaCO_2$. One group suggested that intracranial hypertension in children should be effectively treated almost exclusively with vigorous hyperventilation.[49] Random and 'blind' hyperventilation recently has come into question as a therapeutic intervention because it was found to worsen outcome in adults with severe TBI.[50] Hyperventilation therapy is not recommended in the first 24 hours after head injury, especially as a prophylactic therapy.[51,52] This position is supported by the results of reviews and studies in adults and children that together indicate that hypocapnia in the setting of acute head injury may cause harm by inducing cerebral ischemia. This concern of decreasing perfusion in the early period after injury, has prompted the use of moderate hyperventilation (i.e., $PaCO_2$ of 35 mmHg) that can aid intracranial pressure management without inducing ischemia.[51,53] Current recommendations for $PaCO_2$ management after TBI discourage the use of prophylactic hyperventilation and suggest that hyperventilation should be used only when increased intracranial pressure is refractory to other methods of control.

Inadvertent hyperventilation is extremely common with manual ventilation, regardless of the personnel or setting.[43,54-57] This may have adverse effects on the injured brain through a variety of mechanisms. First, cerebral vasoconstriction with hypocapnia is well documented and can result in global ischemia through a decrease in cerebral blood flow as well as local ischemia, especially in critical areas of brain surrounding the primary injury.[43] Second, positive-pressure ventilation reverses the pattern of negative intrathoracic pressure associated with spontaneous respiration, potentially obstructing venous return and decreasing blood pressure and cardiac output; this occurs to a greater degree with increasing ventilatory rates.[52] Lastly, the increase in mean intrathoracic pressure that accompanies hyperventilation with positive-pressure ventilation can be transmitted in a retrograde fashion through the jugular venous system, raising intracranial pressure as a result. Recent data also suggest that injurious ventilation strategies lead to an increase in cytokine release, endothelial apoptosis, and mortality from both overinflation and from the absence of positive end-expiration pressure. The specific characteristics of prehospital ventilation with regard to each of these factors have not been defined; however, it is possible that a lower end-tidal carbon dioxide value is a surrogate marker for injurious ventilation.

Utilization of continuous end-tidal carbon dioxide (E_TCO_2) monitoring in the prehospital environment as well as in the ED may decrease complications of inadvertent hyperventilation and unrecognized misplaced endotracheal tubes. In a recent study, no unrecognized misplaced intubations were found in patients for whom paramedics used continuous E_TCO_2 monitoring.[58] Failure to use continuous E_TCO_2 monitoring was associated with a 23% unrecognized misplaced intubation rate.[58]

Conclusions

The establishment and maintenance of a patent airway has been the initial step in resuscitation of both children and adults for as long as resuscitation guidelines have existed. Management of the pediatric airway is a skill that is critical in the prehospital environment as well as in the ED. A thorough understanding of a child's anatomy and access to and knowledge of the appropriate equipment and pharmacologic adjuncts enable the ED physician to secure the airway in a timely efficient manner that optimizes the patient's outcome. No other skill is as important![29]

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CNE/CME Objectives

Upon completing this program, the participants will be able to:

a.) discuss conditions that should increase suspicion for traumatic injuries;
b.) describe the various modalities used to identify different traumatic conditions;
c.) cite methods of quickly stabilizing and managing patients; and
d.) identify possible complications that may occur with traumatic injuries.

CNE/CME Instructions

Physicians and nurses participate in this continuing medical education/continuing education program by reading the article, using the provided references for further research, and studying the questions at the end of the article. Participants should select what they believe to be the correct answers, then refer to the list of correct answers to test their knowledge. To clarify confusion surrounding any questions answered incorrectly, please consult the source material. **After completing this activity, you must complete the evaluation form provided and return it in the reply envelope provided in order to receive a letter of credit.** When your evaluation is received, a letter of credit will be mailed to you.

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CNE/CME Questions

1. Which one of the following systemic abnormalities is an important contributor to secondary brain injury?
   A. Hypoxemia
   B. Hypernatremia
   C. Hypothermia
   D. Hypokalemia

2. Which of the following statements regarding pediatric intubation is *false*?
   A. Secondary confirmation of ET placement should be performed routinely.
   B. Hyperventilation should be performed routinely.
   C. End-tidal CO_2 detection is the most common secondary confirmation method.
   D. BVM is an acceptable prehospital technique for managing the pediatric airway.

3. Even with the endotracheal tube in good position, right upper lobe atelectasis is common.
   A. True
   B. False

4. Which of the following statements regarding the pediatric respiratory system is *not* true?
   A. Infants have greater chest wall compliance than adults.
   B. Infants have higher oxygen consumption than adults.
   C. Infants have lower airway resistance than adults.
   D. Infants have fewer alveoli than adults.

5. Pediatric patients:
   A. have a greater tendency to become bradycardic with laryngoscopy.
   B. tolerate supine positioning without desaturation better than adults.
   C. can maintain oxyhemoglobin saturation during a longer period of apnea than adults.
   D. recruit accessory respiratory muscles with greater efficiency than adults.

6. Which of the following statements concerning early management of TBI in children is correct?
   A. The routine use of hyperventilation is indicated because cerebral blood flow is elevated.
   B. There is strong association between adverse outcomes and early hypotension in patients with TBI.
   C. Routein hyperventilation should be initiated in the first 12 hours.
   D. Hyperventilation improves outcomes in children with mild hand injuries.

7. Regarding pediatric airway anatomy:
   A. Children have relatively larger tongues than adults.
   B. The pediatric larynx is located inferiorly to that of an adult.
   C. The epiglottis of a child is similar to that of an adult.
   D. The narrowest point of the infant airway occurs at the level of the vocal cords.

8. Shortly after intubation, a child becomes hypoxemic. Which of the following mechanisms could be responsible?
   A. Pneumothorax
   B. Obstructed endotracheal tube
   C. Accidental extubation
   D. All of the above

9. Excessively low endotracheal tube placement may be associated with atelectasis or pneumothorax.
   A. True
   B. False

10. A short neck, small mandible, large tongue, or high arched palate may indicate a potentially difficult airway.
    A. True
    B. False

Answers
1. A; 2. B; 3. A; 4. C; 5. A; 6. B; 7. A; 8. D; 9. A; 10. A

In Future Issues: **Carbon monoxide poisoning**

Trauma Reports
Evidence-Based Medicine for the ED

TR010107TM

CNE/CME Evaluation — Vol. 8. No. 1. Airway Management in the Pediatric Trauma Patient

Please take a moment to answer the following questions to let us know your thoughts on the CNE/CME program. Fill in the appropriate space and return this page in the envelope provided. **You must return this evaluation to receive your letter of credit. ACEP members — Please see reverse side for option to mail in answers.** Thank you.

CORRECT ⬬ INCORRECT

1. In which program do you participate? ◯ CNE ◯ CME
2. If you are claiming physician credits, please indicate the appropriate credential: ◯ MD ◯ DO ◯ Other ____________
3. If you are claiming nursing contact hours, please indicate your highest credential: ◯ RN ◯ NP ◯ Other ____________

After participating in this program, I am able to:	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
4. Discuss conditions that should increase suspicion for traumatic injuries.	◯	◯	◯	◯	◯	◯
5. Describe the various modalities used to identify different traumatic conditions.	◯	◯	◯	◯	◯	◯
6. Cite methods of quickly stabilizing and managing patients.	◯	◯	◯	◯	◯	◯
7. Identify possible complications that may occur with traumatic injuries.	◯	◯	◯	◯	◯	◯
8. The test questions were clear and appropriate.	◯	◯	◯	◯	◯	◯
9. I am satisfied with customer service for the CNE/CME program.	◯	◯	◯	◯	◯	◯
10. I detected no commercial bias in this activity.	◯	◯	◯	◯	◯	◯
11. This activity reaffirmed my clinical practice.	◯	◯	◯	◯	◯	◯
12. This activity has changed my clinical practice.	◯	◯	◯	◯	◯	◯

If so, how? ____

13. How many minutes do you estimate it took you to complete this activity? Please include time for reading, reviewing, answering the questions, and comparing your answers with the correct ones listed. _______ minutes.
14. Do you have any general comments about the effectiveness of this CNE/CME program?

____

I have completed the requirements for this activity.

Name (printed) ______________________ **Signature**______________________

Nursing license number ***(required for nurses licensed by the state of California)*** ______________________

Please make label address corrections here or PRINT address information to receive a certificate.

PLEASE NOTE: If your correct name and address do not appear below, please complete the section at left.

Account # ______________________

Name: ______________________

Company: ______________________

Address: ______________________

City: ____________ State: ________ Zip ________

Fax: ____________ Phone: ____________

E-mail: ______________________

Optional for ACEP members: In accordance with ACEP requirements, below we provide the option for ACEP members to submit their answers for this CME activity. If you wish to submit answers for this activity, please refer to this issue (Vol.8, No. 1) and circle the correct responses.

1. A
B
C
D

2. A
B
C
D

3. A
B

4. A
B
C
D

5. A
B
C
D

6. A
B
C
D

7. A
B
C
D

8. A
B
C
D

9. A
B

10. A
B

Dear *Trauma Reports* Subscriber:

This issue of your newsletter marks the start of a new continuing medical education (CME) or continuing nursing education (CNE) activity and provides us with an opportunity to review the procedures.

Trauma Reports, sponsored by AHC Media LLC, provides you with evidence-based information and best practices that help you make informed decisions concerning treatment options and physician office practices. Our intent is the same as yours - the best possible patient care.

Upon completing this program, the participants will be able to:

1. discuss conditions that should increase suspicion for traumatic injuries
2. describe the various modalities used to identify different traumatic conditions
3. cite methods of quickly stabilizing and managing patients
4. identify possible complications that may occur with traumatic injuries

Each issue of your newsletter contains questions relating to the information provided in that issue. After reading the issue, answer the questions at the end of the issue to the best of your ability. You can then compare your answers with the correct answers provided in an answer key in the newsletter. If any of your answers were incorrect, please refer back to the source material to clarify any misunderstanding.

This issue includes an evaluation form to complete and return in an envelope we have provided. Please make sure you sign the attestation verifying that you have completed the activity as designed. Once we have received your completed evaluation form we will mail you a letter of credit. This activity is valid 24 months from the date of publication. The target audience for this activity is emergency medicine physicians and nurses, trauma surgeons and nurses.

Those participants who earn nursing contact hours through this activity will note that the number of contact hours is decreasing to 9 annually. This change is due to the mandatory implementation of a 60-minute contact hour as dictated by the American Nurses Credentialing Center. Previously, a 50-minute contact hour was used. AHC Media LLC is accredited as a provider of continuing nursing education by the American Nurses Credentialing Center's Commission on Accreditation.

If you have any questions about the process, please call us at (800) 688-2421, or outside the U.S. at (404) 262-5476. You can also fax us at (800) 284-3291, or outside the U.S. at (404) 262-5560. You can also email us at: customerservice@ahcmedia.com.

On behalf of AHC Media, we thank you for your trust and look forward to a continuing education partnership.

Sincerely,

Brenda Mooney
Vice-President/Group Publisher
AHC Media LLC