Bariatric CT Imaging: Challenges and Solutions[1]

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SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Explain the physical limitations to accommodating bariatric patients in CT suites.
- Describe commonly encountered CT artifacts at bariatric imaging.
- Discuss the pitfalls in acquiring contrast-enhanced CT images of bariatric patients.

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The obesity epidemic in the adult and pediatric populations affects all aspects of health care, including diagnostic imaging. With the increasing prevalence of obese and morbidly obese patients, bariatric computed tomographic (CT) imaging is becoming common in day-to-day radiology practice, and a basic understanding of the unique problems that bariatric patients pose to the imaging community is crucial in any setting. Because larger patients may not fit into conventional scanners, having a CT scanner with an adequate table load limit, a large gantry aperture, a large scan field of view, and a high-power generator is a prerequisite for bariatric imaging. Iterative reconstruction methods, high tube current, and high tube voltage can reduce the image noise that is frequently seen in bariatric CT images. Truncation artifacts, cropping artifacts, and ring artifacts frequently complicate the interpretation of CT images of larger patients. If recognized, these artifacts can be easily reduced by using the proper CT equipment, scan acquisition parameters, and postprocessing options. Lastly, because of complex contrast material dynamics, contrast material–enhanced studies of bariatric patients require special attention. Understanding how the rate of injection, the scan timing, and the total mass of iodine affect vascular and parenchymal enhancement will help to optimize contrast-enhanced studies in the bariatric population. This article familiarizes the reader with the challenges that are frequently encountered at CT imaging of bariatric patients, beginning with equipment selection and ending with a review of the most commonly encountered obesity-related artifacts and the technical considerations in the acquisition of contrast-enhanced images.

Introduction

The prevalence of obesity in the adult and pediatric populations has increased continuously since the 1970s, with more than 33.8% of adults with obesity in the United States today (1). Obesity-related health care expenditures have been estimated at as much as $147 billion annually (2). Despite recent evidence that obesity rates are beginning to plateau, current projections estimate that 42%–51% of the U.S. population will be obese by 2030 (1,3). The proportional increase in the rate of morbid obesity, which is defined as a body mass index of 40 or more, is even higher; and current estimates herald a rise in the morbidly obese population from 4.9% to 11.1% during the next 20 years, an increase of nearly 130% (3).

Given the extent of the obesity epidemic affecting the U.S. population, health care–related issues in this patient group affect all aspects of health care, including diagnostic imaging. Among the many challenges that bariatric patients pose to the radiology community are the physical barriers related to patient access. Many cross-sectional imaging suites are simply not equipped to accommodate or safely

TEACHING POINTS

- The CT scanners appropriate for bariatric imaging typically have high table load limits, wide gantry apertures, larger scan fields of view, and more powerful generators. The following values represent the maximum CT scanner parameters from leading scanner manufacturers that are available for bariatric imaging: table load limit, 308 kg (680 lb); gantry aperture, 85 cm (90-cm apertures are available on radiation oncology scanners); scan field of view, 65 cm (85-cm scan field of view options are available on radiation oncology scanners); tube current, 835 mA; and tube voltage, 140 kVp. In addition, major scanner manufacturers and some third-party vendors offer iterative reconstruction options to assist in generating the highest-quality images from the noise-limited datasets typically encountered at bariatric CT imaging of bariatric patients.
- Image noise, or quantum mottle, is the most common imaging artifact encountered in the bariatric population, and it can be minimized by sequentially increasing the tube current–time product and the tube voltage.
- Truncation and cropping artifacts remain a substantial problem in CT scanning of bariatric patients and can be avoided by maximizing the reconstruction field of view of the study and by using extended field of view options.
- The easiest way to compensate for the ring artifact is to increase the tube current or voltage (or both), at the expense of increasing the patient's dose. Detector calibration should be performed according to the manufacturer's guidelines to prevent generation of the ring artifact by miscalibrated detectors.
- Contrast-enhanced studies in bariatric patients generally require intravenous access suitable for high rates of injection, precise scan timing, and a high mass of iodine delivered to the target parenchymal organ.

maneuver morbidly obese patients, a problem that results in longer turnover times and an increased risk for occupational injury to the hospital staff. Further, many examinations are cancelled because of patients' inability to fit into conventional CT or magnetic resonance imaging equipment, which leads to delayed diagnosis and treatment.

Inherent diagnostic limitations related to the physics of CT imaging are also unique to the bariatric patient group. For example, obese and morbidly obese patients require larger numbers of incident photons to generate an adequate signal-to-noise ratio, thus resulting in higher radiation exposure. Images of bariatric patients are susceptible to confounding artifacts, which can increase the difficulty of interpretation and decrease the conspicuity of pertinent pathologic conditions. The artifacts may also lead to repeat examinations, which result in higher cumulative doses and increased provider costs.

In this article, we explore the challenges inherent in CT imaging of bariatric patients, examining factors ranging from scanner selection to image reconstruction. Special attention is paid to the most commonly encountered artifacts in bariatric imaging, as well as techniques to reduce these artifacts and improve the diagnostic yield of CT examinations. Lastly, we discuss the unique contrast material dynamics in the bariatric population and explore ways to optimize the use of intravenous contrast material in contrast-enhanced CT studies.

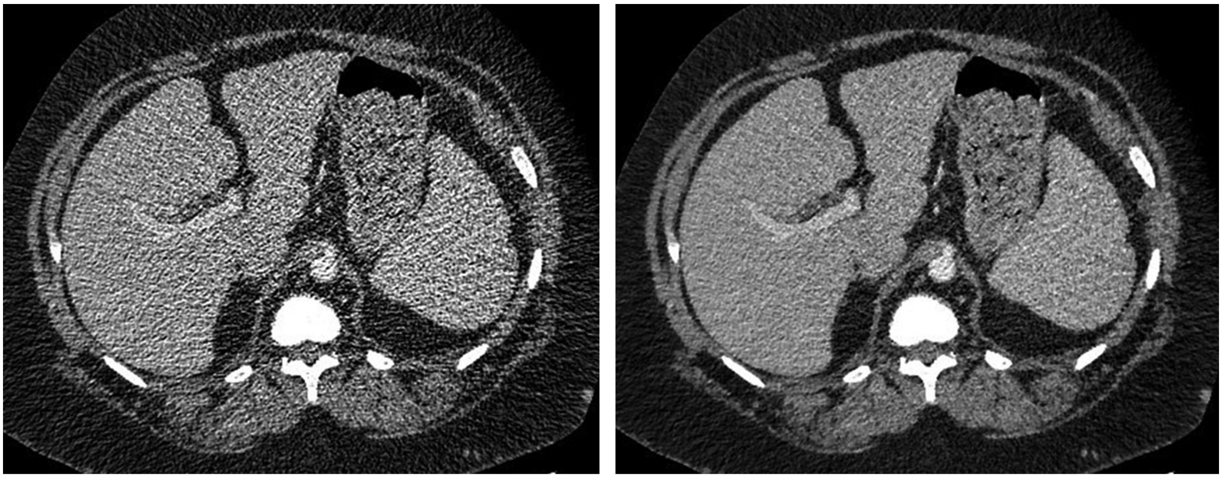
CT Options for Bariatric Imaging

According to a 2008 national survey, only 10% of nonacademic hospitals and 28% of academic hospitals with emergency departments were equipped with CT scanners designed to accommodate bariatric patients (4). The CT scanners appropriate for bariatric imaging typically have high table load limits, wide gantry apertures, larger scan fields of view, and more powerful generators. The following values represent the maximum CT scanner parameters from leading scanner manufacturers that are available for bariatric imaging: table load limit, 308 kg (680 lb); gantry aperture, 85 cm (90-cm apertures are available on radiation oncology scanners); scan field of view, 65 cm (85-cm scan field of view options are available on radiation oncology scanners); tube current, 835 mA; and tube voltage, 140 kVp. In addition, major scanner manufacturers and some third-party vendors offer iterative reconstruction options to assist in generating the highest-quality images from the noise-limited datasets typically encountered at bariatric CT imaging of bariatric patients.

CT Scanner Characteristics

The table load limit refers to the maximum weight supported by the scanner table. Traditionally, older units were not designed to accommodate patients weighing more than 205 kg (450 lb). Even if the table could support bariatric patients of such proportions, the table motor often could not advance the patient through the gantry at a uniform speed (5). Most modern CT manufacturers now offer tables with increased capacity, equipped with motors that are capable of accommodating patients weighing as much as 308 kg (680 lb).

The gantry aperture refers to the diameter of the opening in the circular frame housing the tube, the collimating system, and the detector array. Compared with the older models of CT scanners, in which apertures measured 70 cm or less, modern units are larger, with apertures ranging from 75 to 85 cm, depending on the manufacturer and model. The radiation oncology department may boast scanners with apertures as large as 90 cm, but these scanners are not intended for routine diagnostic imaging. Regardless of the model, as much as 19 cm of the gantry aperture may be occupied by the CT table itself, which leads to problems in accommodating larger patients (6).



a. b.

Figure 1. Image noise with filtered backprojection compared with iterative reconstruction. Axial CT images obtained at the level of the liver and reconstructed at a 0.67-mm section thickness by using the filtered backprojection method **(a)** and the iterative reconstruction method **(b)** show that the image noise has substantially decreased with implementation of the iterative reconstruction algorithm.

The scan field of view refers to the area from which data are collected and defines the maximum in-plane area that can be accurately reconstructed into an image. The scan field of view can never exceed the gantry aperture. Options for the scan field of view range from 50 to 65 cm for most modern CT scanners. Options for an extended field of view can improve depiction of the tissues outside the edges of the scan field of view but may not be supported by the manufacturer for diagnostic purposes. At bariatric imaging, a small scan field of view can lead to undesirable truncation artifacts, which are discussed in the "Truncation and Cropping Artifacts" section.

The generator determines the maximum tube voltage–tube current combination that can be applied for any given CT scanner. If a generator is underpowered, the scanner will not be able to generate enough radiation to sufficiently penetrate a bariatric patient, which may lead to noisy images. Fortunately, most modern CT scanners can produce tube currents in the 800-mA range and can provide voltages as high as 140 kVp.

Image Reconstruction

Conventional reconstruction methods have classically used filtered backprojection, which is the fastest and least computationally intensive method to generate an image. Unfortunately, reconstruction kernels used in filtered backprojection result in loss of image resolution and, as such, are not optimal for reconstructing the noisy datasets associated with bariatric imaging.

Iterative reconstruction is a different class of reconstruction algorithms that use precise statistical modeling to correct for quantum fluctuations and achieve more-efficient noise removal than filtered backprojection methods. Iterative reconstruction is generally more computationally intensive and slower than filtered backprojection, but it can produce substantial reductions in noise without appreciable decreases in image resolution (Fig 1) (7). In the bariatric population, iterative reconstruction should be used whenever possible, because noise reduction allows for the acquisition of quality images at lower radiation doses (8).

Several vendor-specific variants of iterative reconstruction are available with sequential generational upgrades, each providing progressively more accurate denoising and increased spatial resolution. The newer-generation iterative reconstruction algorithms—the so-called model-based versions—are more effective at denoising and provide more faithful reconstruction by specifically modeling detector response, taking into account the precise scanner optics (9). Iterative reconstruction options from the leading CT manufacturers are summarized in the Table. Alternative postprocessing noise-filtering software options are also available from several developers. These software options are not unit specific and can be used with almost all scanner models, including older CT platforms, for which computationally intensive vendor-specific iterative reconstruction algorithms may not be available (9–15).

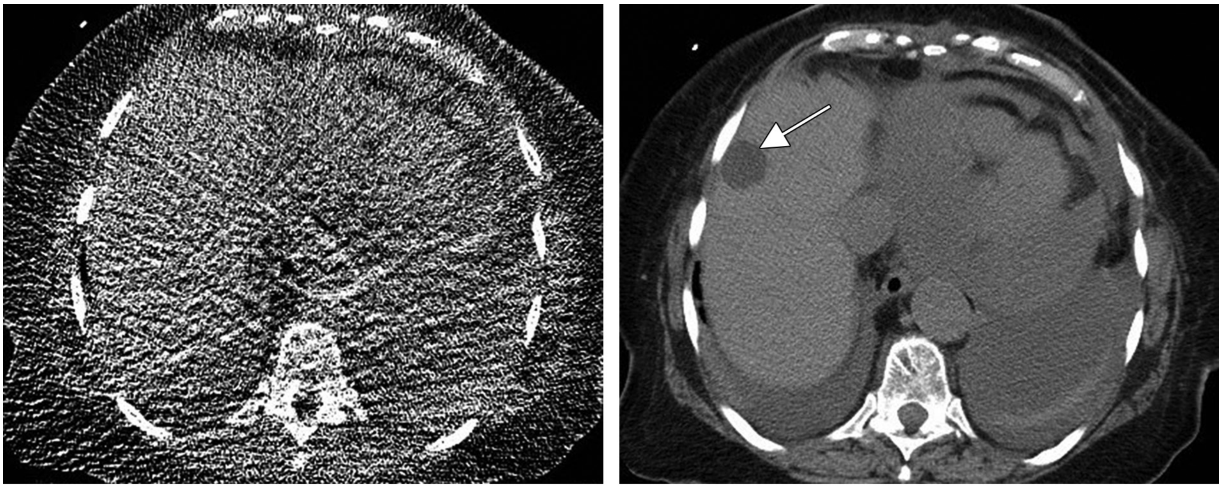
Common CT Artifacts at Bariatric Imaging

Quantum Mottle and Noise

Image noise, or quantum mottle, is the most common imaging artifact encountered in the bariatric population, and it can be minimized by sequentially increasing the tube current–time

Iterative Reconstruction Options Available from Different CT Scanner Manufacturers

Manufacturer	Statistical Iterative Reconstruction	Model-based Iterative Reconstruction
Philips Healthcare (Cleveland, Ohio)	iDose^4	Iterative Model Reconstruction (IMR)
Siemens Healthcare (Malvern, Pa)	Iterative Reconstruction in Image Space (IRIS), Sinogram Affirmed Iterative Reconstruction (SAFIRE)	Advanced Modeled Iterative Reconstruction (ADMIRE)
Toshiba Medical Systems (Tochigi, Japan)	Adaptive Iterative Dose Reduction (AIDR, AIDR+)	Adaptive Iterative Dose Reduction 3D (AIDR 3D)
GE Healthcare (Milwaukee, Wis)	Adaptive Statistical Iterative Reconstruction (ASiR)	Veo



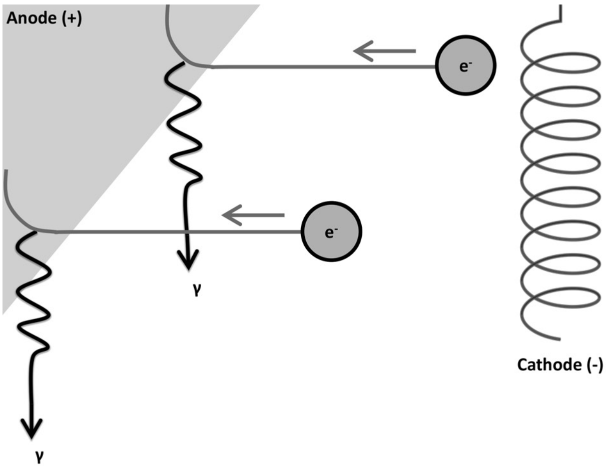
a. **b.**

Figure 2. Image noise at different settings for tube current–time product and tube voltage. Axial CT images obtained at the level of the liver acquired by using settings of 130 mAs and 80 kVp **(a)** and settings of 750 mAs and 120 kVp **(b)**. The noise level in **b** is reduced dramatically, allowing depiction of a low-attenuation liver lesion (arrow). The radiation dose to the patient during the scanning procedure for **b** was much higher.

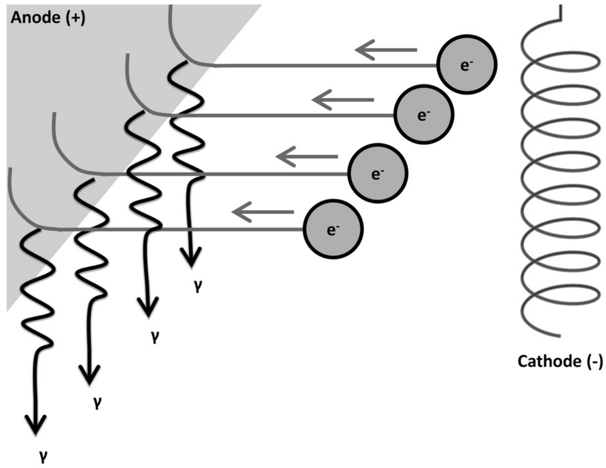
product and the tube voltage (Fig 2). Quantum mottle results from an insufficient number of photons reaching the detector, and quantum mottle increases exponentially with increasing patient thickness because of greater photon attenuation (16,17). For a noise-limited system such as CT, the noise is inversely proportional to the square root of the number of photons used to create the image. If the noise is particularly severe, especially along specific projections, then it may be referred to as "photon starvation." With abdominal and thoracic scanning, this artifact is usually most pronounced along the mediolateral axis of the patient because of the increased body thickness in this dimension.

Increasing the tube current (commonly referred to as "mA" for milliamperes) increases the number of photons hitting the patient and thus directly affects the number of photons that are ultimately able to reach the detector to create the image. On the basis of the proportionality described previously, quadrupling the number of photons that pass through the patient and reach the detector will decrease the image noise by half. The noise reduction, however, comes at a cost of an increased radiation dose, which is linearly proportional to the tube current; if all other variables are fixed, doubling the tube current will double the patient dose (Fig 3). The increase in the tube current is limited by the heating constraints of the system and by the power generator of the CT scanner, as mentioned previously. When scanning a bariatric patient, the tube current should be the first parameter increased if the noise is excessive. Fortunately, most modern scanners allow the operator to implement automatic tube current modulation that automatically adjusts the tube current on the basis of the thickness of the patient (7).

Increasing the time per rotation also reduces the noise, because more photons hit the patient and ultimately reach the detector. This parameter is measured in seconds and represents the *s* in the familiar unit of measure of milliamperes per

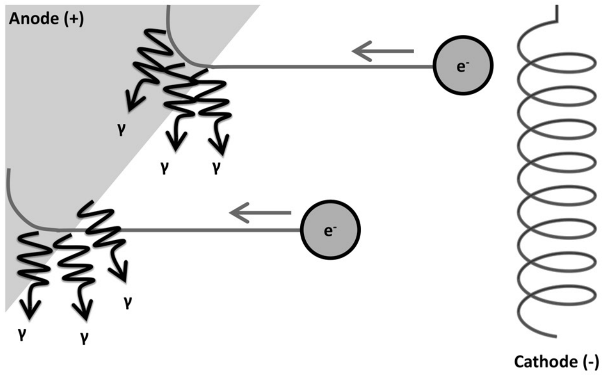


a.



b.

Figure 3. Diagrams representing the differences for increases in the tube current and tube voltage. **(a)** Diagram shows that electrons *(e⁻)* are accelerated from the cathode toward the anode at a given tube current and tube voltage. Bremsstrahlung interactions within the anode result in the production of x-ray photons (γ). **(b)** Diagram shows that if the tube current is doubled, twice as many electrons interact with the anode, and twice as many photons are produced. **(c)** Diagram shows that if the tube voltage is doubled, the amount of x-rays produced per bremsstrahlung interaction increases in a nonlinear fashion.



c.

second (mAs) for the tube current–time product. Similar to the tube current, the patient radiation dose is linearly proportional to the time per rotation. The downside of increasing this parameter is that the total scanning time will also be increased, making it more likely that the patient will move during the scan.

Pitch refers to the distance traveled by the scanner table in one gantry rotation divided by the beam collimation (18). When the pitch is low, the table moves more slowly during each gantry rotation, resulting in a higher number of photons hitting the patient at any given section. Similar to increasing the time per rotation, lowering the pitch results in less-noisy images at the expense of increased scanning time and increased radiation dose to the patient.

Tube voltage (measured in kilovolts peak [kVp]) refers to the maximum voltage applied across an x-ray tube during the scan. Increasing the tube voltage results in a higher energy spectrum of the primary photons, allowing better photon penetration and decreased noise. In addition, when the tube voltage is increased, the efficiency of bremsstrahlung interactions within the tube is also increased. As a result, more photons are produced and hit the detector, which leads to lower image noise. In contradistinction to the linear relationship between the tube current and the radiation dose, increasing the tube voltage will increase the dose in a nonlinear fashion (Fig 3). In addition, when increasing the tube voltage, one should expect a decrease in the image contrast that is due to an inverse relationship between these two variables. Therefore, in certain scans in which high image contrast is desired, increasing the tube voltage may not be appropriate.

Truncation and Cropping Artifacts

When the x-ray beam passes through the patient, it is attenuated by the entire soft-tissue thickness located within the gantry. For larger patients, excess soft tissues may fall outside the scan field of view, but the scanner reconstruction algorithm will assume that all of the attenuation occurred within the scan field of view. As a result, the periphery of the reconstructed image will appear to have substantially higher attenuation, generating a truncation artifact (Fig 4). This artifact can be potentially overcome by applying the options for an expanded field of view to include all of the soft tissues (19); however, the acquired images may not be of diagnostic quality, thus only partially mitigating the problem.

Cropping artifacts occur when portions of the patient fall outside the reconstruction field of view if it is selected to be smaller than the scan field of view. Cropping is similar to truncation in that it may exclude relevant anatomic structures

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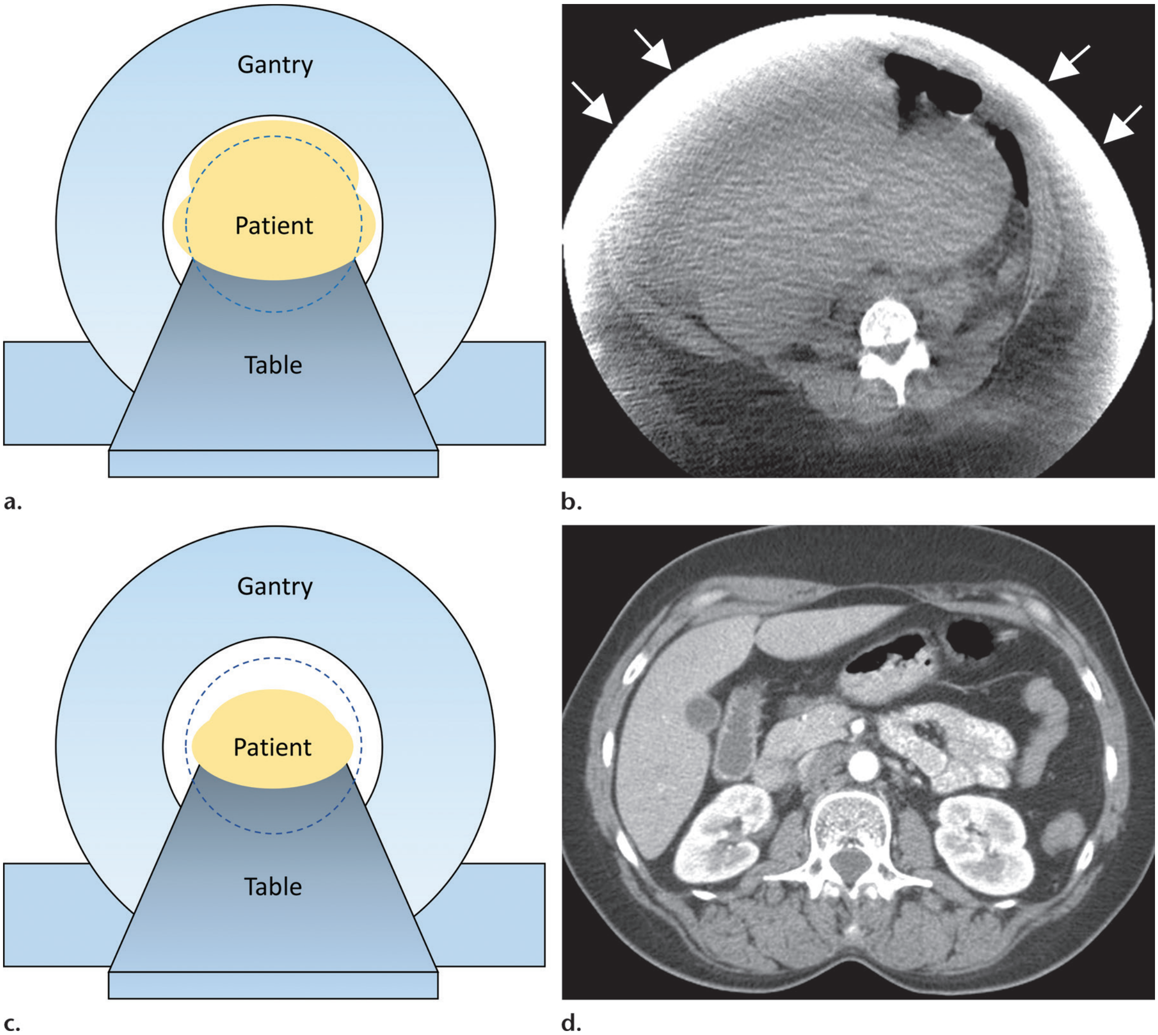


Figure 4. Truncation artifact. **(a, b)** Diagram of the scanner setup **(a)** and axial CT image **(b)** of a morbidly obese 36-year-old woman show severe truncation artifact (arrows in **b**) resulting from soft tissues positioned outside the scan field of view (dashed line in **a**). **(c, d)** For comparison, a diagram of the scanner setup **(c)** and axial CT image **(d)** of a smaller individual show that all of the soft tissues are included within the scan field of view (dashed line in **c**).

from the field of view. Commonly excluded peripheral findings include soft-tissue metastases, fluid collections, abdominal wall hernias, and even foreign bodies in the setting of trauma (Fig 5).

Truncation and cropping artifacts remain a substantial problem in CT scanning of bariatric patients and can be avoided by maximizing the reconstruction field of view of the study and by using extended field of view options (5,20). In addition to missed pathologic conditions, these artifacts may necessitate repeat examinations, further increasing the patient's cumulative radiation dose. In dual-modality imaging with positron emission tomography (PET) and CT (PET/CT), truncation also affects measurements of the standardized uptake value, which renders it difficult or impossible to accurately quantify the metabolic activity of pertinent pathologic findings (21). Truncation correction algorithms are available on multiple scanner models and can be used to suppress the bright halo, with small residual errors (22). However, even after correction, pathologic findings that fall outside the field of view can be obscured.

Ring Artifact

During a CT examination, the rotation of the tube-detector unit results in each detector registering photons that travel at a specific distance from the center of rotation. Errors in detector calibration as small as 0.1% may cause backprojection along the photon path and give rise to a ring artifact. Ring artifact is never completely eliminated, because it is virtually impossible to calibrate the detectors with 100% precision. In the general population, this artifact is usually undetectable because high noise and photon starvation rarely pose an issue. In bariatric patients, the minute differences in detector sensitivity may

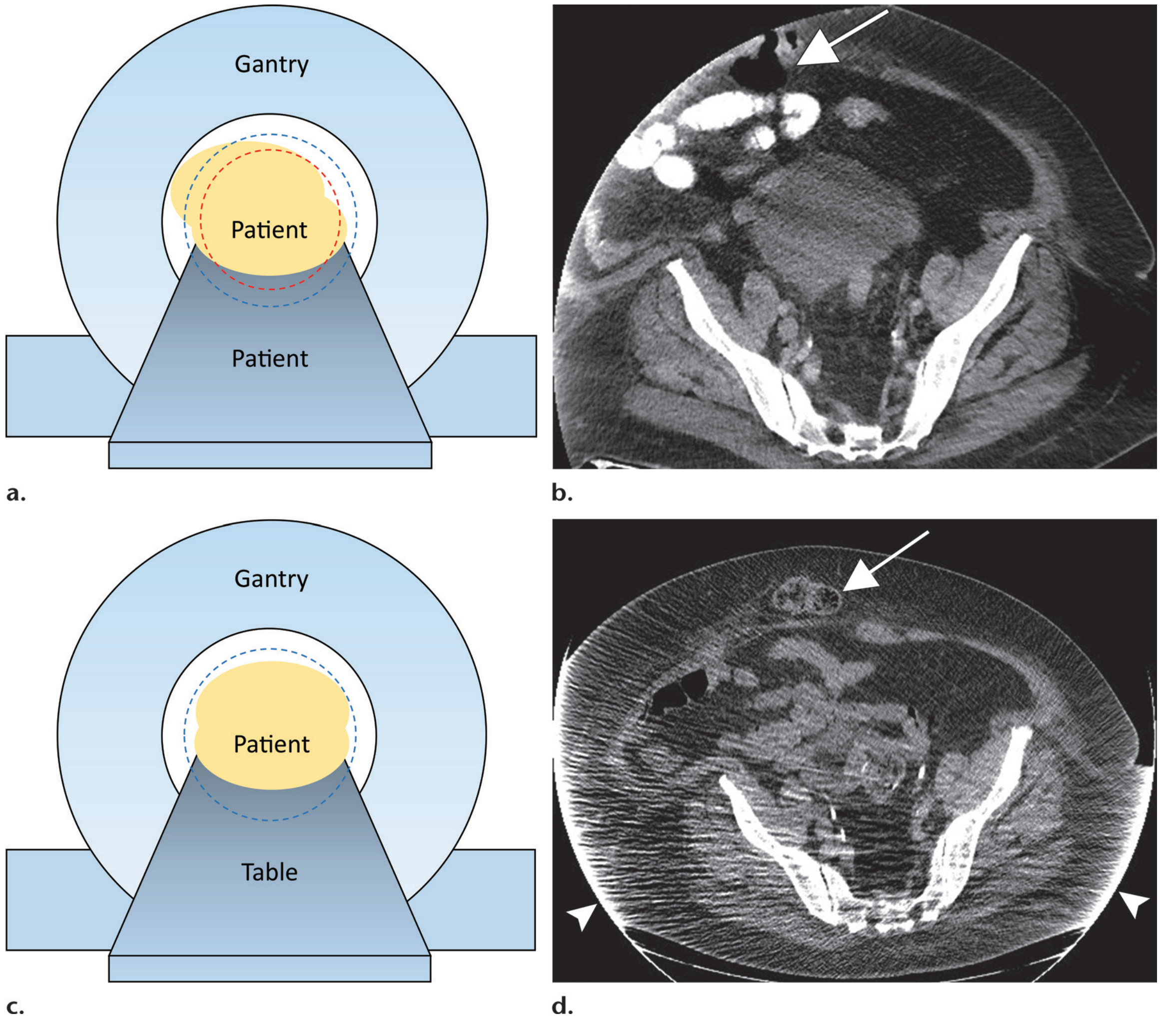


Figure 5. Cropping artifact. **(a, b)** Diagram of the scanner setup **(a)** and axial CT image **(b)** of a morbidly obese 75-year-old woman show the cropping artifact. Subcutaneous soft tissues and the right abdominal wall were excluded from the reconstruction field of view (red dashed line in **a**), and a ventral hernia (arrow in **b**) at the periphery of the image was nearly missed. Blue dashed line in **a** = scan field of view. **(c, d)** Diagram of the scanner setup **(c)** and axial CT image **(d)** of the same patient, who was repositioned and rescanned, with the reconstruction field of view expanded to match the diameter of the scan field of view (blue dashed line in **c**). All of the soft tissues are now included, and the ventral hernia (arrow in **d**) is much more conspicuous. Posterolateral truncation artifact (arrowheads in **d**) is also seen.

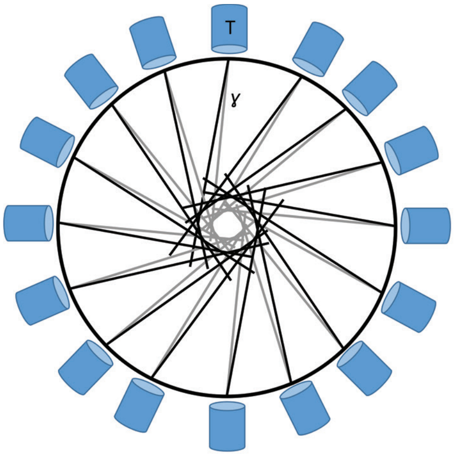
become exaggerated by the problem of quantum mottle and thus may make the ring artifact apparent even with appropriate scanner calibration (Fig 6). Peripherally located rings may not compromise image quality; however, a centrally located ring artifact can form a "smudge" that may obscure or mimic pathologic conditions (23,24).

The easiest way to compensate for the ring artifact is to increase the tube current or voltage (or both), at the expense of increasing the patient's dose. Detector calibration should be performed according to the manufacturer's guidelines to prevent generation of the ring artifact by miscalibrated detectors. Software algorithms are being developed for automated correction of ring artifact, but they are not widely available at this time (25).

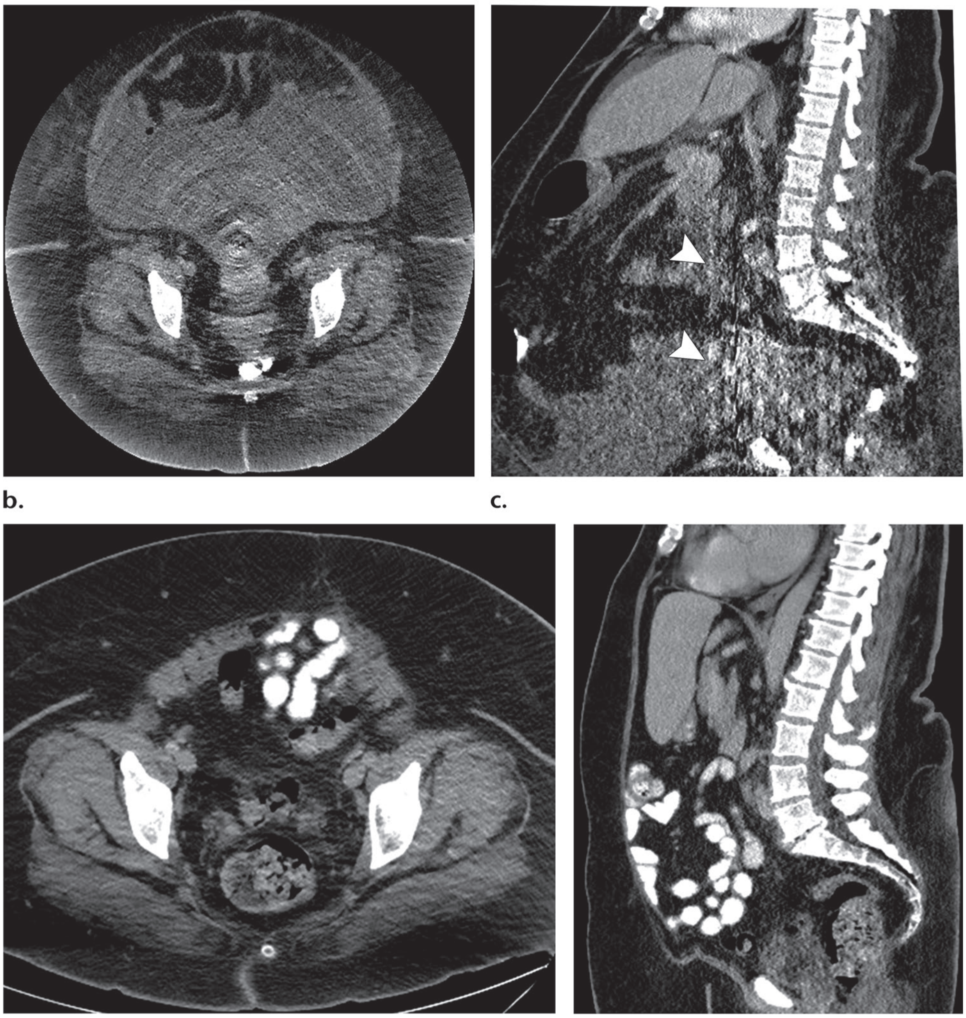
Contrast-enhanced CT in the Bariatric Population

General Considerations

Contrast-enhanced studies in bariatric patients generally require intravenous access suitable for high rates of injection, precise scan timing, and a high mass of iodine delivered to the target parenchymal organ. Contrast-enhanced CT scans can be divided into two broad categories: studies requiring vascular enhancement and studies in which a high degree of parenchymal enhancement is desired. The main patient-related factors affecting vascular enhancement are the cardiac output and the intravascular volume. In contradistinction, parenchymal enhancement depends primarily on the total mass of iodine delivered to the target parenchymal organ, with a secondary



a.



b. c. d. e.

Figure 6. Ring artifact. **(a)** Diagram shows that as the x-ray tube *(T)* rotates around the gantry, different photon beams (γ) at different angles intersect to form rings in the center of the image. **(b, c)** Axial **(b)** and sagittal **(c)** CT images show the ring artifact in an obese 50-year-old woman. On the sagittal CT image, the artifact (arrowheads in **c**) is seen as vertical streaks at the center of the image. **(d, e)** Axial **(d)** and sagittal **(e)** CT images of the same patient obtained 6 months later after she had sustained a 41-kg (90-lb) weight loss show resolution of the ring artifact. At both imaging examinations, the patient was imaged on the same scanner at identical kilovoltage (kVp) and tube current–time (mAs) settings with proper detector calibration.

dependence on rate. Contrast material dynamics are unique in bariatric patients because of the increased body weight, which correlates directly with increased intravascular and interstitial volume. If high doses of contrast material cannot be tolerated by the bariatric patient because of renal insufficiency, scanning at lower tube voltages may be appropriate in select cases, maximizing the k-edge effect of iodine and increasing the attenuation value while using a lower volume of contrast material.

Intravenous Access

Obtaining intravenous access in a morbidly obese patient may be difficult because of the increased soft-tissue thickness. Because bariatric patients require high injection rates, intravenous access should be established in a more-central larger-caliber vein, because rapid injection into smaller veins (ie, veins of the dorsal part of the hand) may result in extravasation of contrast material or venous trauma. Antecubital venous access is preferred, and central venous access may be used if available. Contrast enhancement may occur 4–6 seconds earlier with a central venous injection, compared with an antecubital vein injection (26). Because of this earlier enhancement, the use of bolus-trigger and bolus-tracking software is crucial for accurate scan timing.

Several commercially available cannulas facilitate intravenous administration of contrast material at high rates in bariatric patients. The cannula should be short, with a preferred luminal diameter of 18 gauge or larger, to achieve adequate infusion rates for vascular enhancement in bariatric patients (27). Certain intravenous catheters have fenestrated side walls that allow a faster flow with smaller cannula diameters. In the findings of a recent randomized controlled trial that compared the performance of an 18-gauge nonfenestrated catheter to that of a 20-gauge fenestrated catheter, investigators concluded that both catheters allowed similar infusion rates and produced comparable degrees of aortic enhancement (28). Use of these specialized catheters may be beneficial in obese patients, who often have difficult peripheral access, because equal flow rates can be achieved with smaller cannula diameters.

Vascular Enhancement

The key physical parameters that determine early enhancement in the central arteries are the cardiac output and the intravascular blood volume. The degree of vascular enhancement is inversely related to the cardiac output because of the variable hemodilution effect on the bolus of contrast material (29). Because heart failure is more common in bariatric patients, compared with the general population, their cardiac output is highly variable, and a test bolus is usually necessary to determine the ideal scan timing.

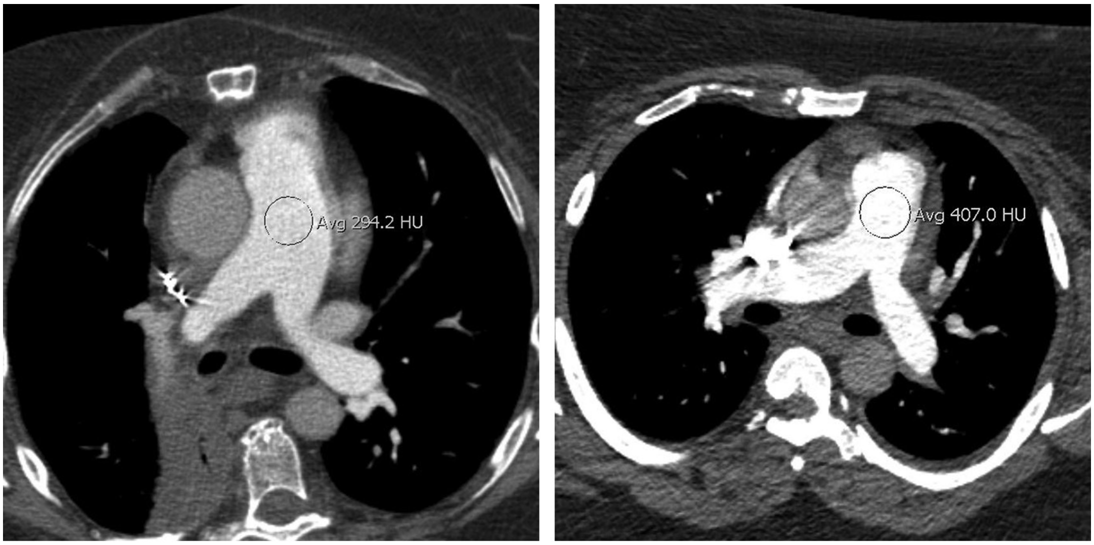
Aside from the cardiac output, the biggest determinant of arterial enhancement is the body weight, which correlates directly with the blood volume. A patient with a higher body mass index (and thus a larger blood volume) will have less enhancement from the same volume of contrast material as a result of hemodilution. Other bulk flow factors, including vascular resistance and vessel capacitance, also come into play. Assuming equivalent cardiac output in the obese and nonobese individuals, the larger patient will have a greater vascular volume to opacify and, as such, will have a larger hemodilution effect and therefore require more contrast material to achieve the desired attenuation values (30).

After hemodilution effects are accounted for with a higher contrast load, the next determinant of adequate arterial enhancement at bariatric imaging is the iodine flux. In the simplest terms, the peak attenuation within the central arteries (assuming negligible recirculation and low initial redistribution) can be thought of as predominantly dependent on flow. To achieve higher arterial enhancement and to compensate for the increased image noise at CT imaging of bariatric patients, one can increase the concentration of the contrast material, increase the delivery rate, or increase both to achieve higher iodine flux across the cross section of the target vascular bed (30). Commercially available contrast materials in the United States have iodine concentrations of as much as 370 mg of iodine per milliliter, and administration rates as high as 6 mL/sec may be appropriate for imaging of certain bariatric patients. In addition, bolus shaping with a saline flush and careful scan timing are also extremely important for optimal results (31–33).

Parenchymal Enhancement

Parenchymal enhancement is concerned primarily with the total mass of iodine delivered to the target organ, including the intravascular and interstitial compartments. Peak parenchymal attenuation curves correlate more directly with the total injection time and the delivered bulk mass of iodine than with the injection rate (30), implying that parenchymal enhancement is primarily dose dependent rather than flow dependent. Because of this relationship, it is possible to achieve adequate parenchymal enhancement even when high flow rates are not practical (eg, a morbidly obese patient with limited peripheral vascular access) by delivering an adequate mass of iodine during a longer injection time.

An important pitfall of this principle concerns hepatic imaging, in which an extremely long injection can result in decreased conspicuity of hypovascular lesions. It is well documented that hypovascular hepatic masses are most conspicuous during the portal venous phase, when avid enhancement of the hepatic parenchyma provides stark contrast between the liver and the lesion (34). If the injection time is prolonged markedly, CT scan acquisition may be delayed into the equilibrium phase, when enough contrast agent recirculation through the hepatic artery into the hypovascular lesion will result in decreased conspicuity of the lesion (35). Fixed injection times are therefore advised



a. b.

Figure 7. Differences in vascular enhancement at different tube voltages. **(a)** Axial CT image of a 111-kg (244-lb) 52-year-old woman who received 75 mL of contrast material and was scanned at 120 kVp shows that the attenuation of the pulmonary artery was 294.2 HU. **(b)** Axial CT image of a 119-kg (262-lb) 47-year-old man who received the same amount of the same contrast material at an identical rate of injection but was scanned at 100 kVp shows that the attenuation of the pulmonary artery was 407.0 HU, approximately 38% higher than the value in **a**.

for larger patients, with higher rates of injection used to deliver the appropriate amount of iodine before reaching the equilibrium phase (30).

Historically, the mass of iodine needed for adequate parenchymal enhancement has been adjusted proportionally on the basis of the body weight alone (eg, if the patient weight doubled, twice the amount of iodine was administered). This model, however, may overestimate the iodine dose in morbidly obese patients because of a disproportionate increase in the fat content relative to the extracellular volume, and such overestimation can pose a risk to the patient in cases of renal insufficiency. In the results of several studies, investigators have shown that contrast dose adjustment on the basis of lean body weight or body surface area may be more appropriate in bariatric patients (36–39), and software for automatic calculation of these parameters from a patient's height and weight is available on the majority of commercial CT scanners.

Scanning at Lower Tube Voltage

Another way of improving vascular and parenchymal contrast enhancement without substantially increasing the dose of administered contrast material is to scan at a lower tube voltage (Fig 7). Using voltages of 100 kVp or less results in higher CT attenuation of contrast material because of the photon energies being closer to the k edge of iodine (17). For example, an iodine concentration of 5 mg/mL will produce approximately 130 HU of contrast enhancement at 120 kVp and approximately 205 HU of contrast enhancement at 80 kVp (29). Thus, the amount of contrast material required to achieve similar degrees of vascular and parenchymal enhancement is substantially lower at 80 kVp, compared with 120 kVp.

Unfortunately, the application of this principle is limited in the bariatric population, because lowering the tube voltage will invariably result in noisy images. It may, however, be possible in select cases when other methods of reducing image noise (ie, appropriate tube current, pitch, section thickness, and iterative reconstruction) are implemented.

Conclusion

With the increasing prevalence of obesity, bariatric CT imaging is becoming common in day-to-day radiology practice. Bariatric patients present numerous unique challenges, and basic knowledge of scanner characteristics, image reconstruction, and obesity-related artifacts, both in nonenhanced and contrast-enhanced studies, is essential for acquisition of diagnostic-quality CT images in day-to-day radiology practice.

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