Chapter 3

Delivery of Contrast Media for MDCT

Proper delivery of iodinated contrast is extremely important for MDCT. All of the amazing advantages of MDCT can be nullified by improper contrast administration. The faster acquisitions possible with MDCT have many benefits for contrast delivery, including greater coherency of the contrast bolus and the ability to reduce contrast dose. At the same time, these faster acquisitions can be less forgiving, and it is possible to completely miss or outrun a contrast bolus.

To understand protocols for contrast administration, it is important to consider early contrast medium (CM) dynamics. When CM is injected intravenously, it travels from the veins at the injection site to the right heart, the pulmonary arteries, and then to the pulmonary veins and the left heart before it reaches the arterial system for the first time (*first pass*). After the CM is distributed throughout the body, it reenters the right heart (equilibrium phase). Therefore, what we identify as arterial enhancement for CTA includes both a first-pass and an equilibrium or recirculation contribution. The first-pass effect produces much denser contrast enhancement as a result of less dilution (Figure 3.1). As a result of this, uniphasic (constant rate) injections do not lead to an arterial enhancement plateau, but rather to a hump-shaped time enhancement curve. Plateau-like arterial enhancement can only be achieved with biphasic or multiphasic injection protocols.

Injection duration also affects the cumulative arterial enhancement and peak enhancement. Both will be smaller if the injection duration is shortened. The maximal arterial enhancement response is also directly proportional to the iodine administration rate (*iodine flux*) and can be controlled by increasing the injection rate and/or the iodine concentration of the contrast used. In practical terms, similar peak enhancement can be obtained by using lower density contrast (300 mg I/mL) at a faster rate or higher density contrast (350 mg I/ml or 370 mg I/ml) at a lower rate.

When designing contrast administration protocols, the main variables to consider are amount and density of contrast, rate of injection, proper timing of the bolus, and whether to use a uniphasic or multi-

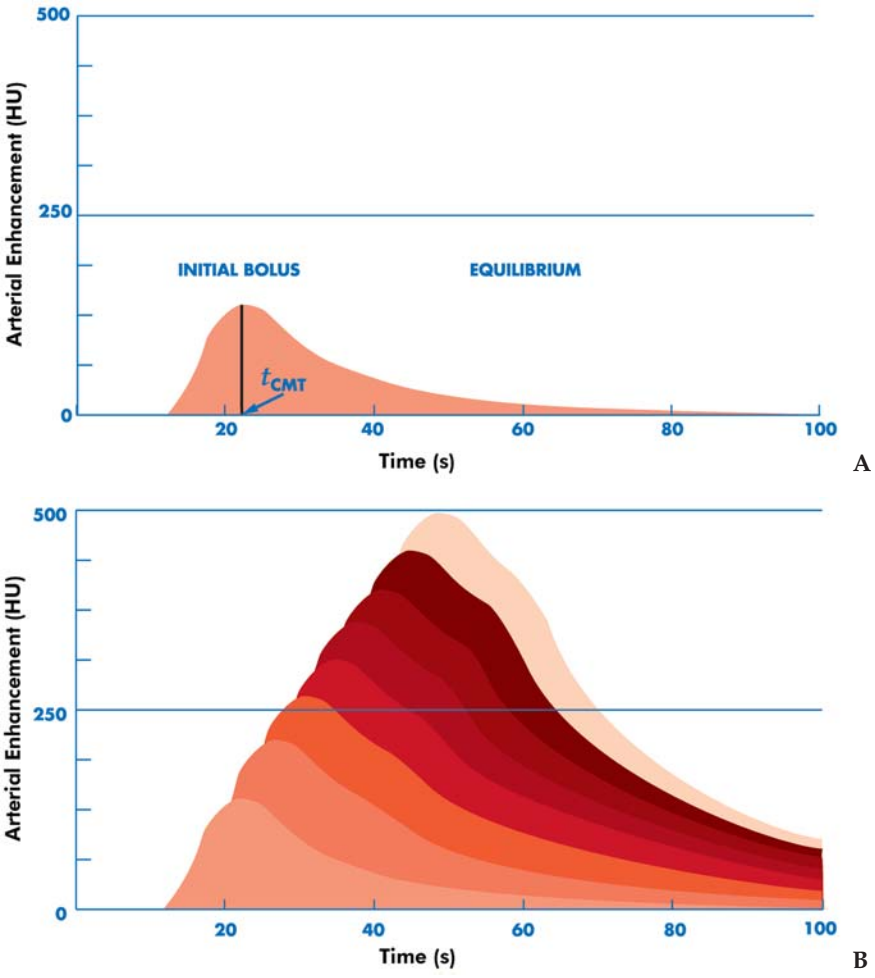

Figure 3.1. Contrast enhancement curve. Demonstration of first-pass effect and continued uniphasic contrast injection over time. (A) A short, rapid contrast injection such as a test bolus will produce a rapid increase in arterial density related to the first-pass effect with progressive decay in density in the equilibrium phase. The time to peak arterial enhancement is demonstrated as t_{CMT}. (B) A rapid, continuous contrast injection produces progressively increasing arterial density over the duration of the injection related to a summation of first-pass and equilibrium phases as the contrast recirculates throughout the body.

phasic injection. For sites that have a dual head injector, there is also the impact of a saline flush injection to consider.

Scan Timing

Successful CT angiography requires careful attention to scan timing. Fortunately, all current 16-slice scanners offer contrast timing programs that can eliminate most of the guesswork from the process. The process

can work several different ways, depending on the scanner and the option chosen. The purpose of these programs is to take away the guesswork in the calculation of the patient's contrast media transit time (t_{CMT}).

Test Bolus Method

The test bolus method uses a small test injection and multiple low dose scans performed over the artery of interest until the contrast is visualized. This gives an accurate value of time to arrival for the contrast in that artery. The t_{CMT} is defined as the time to peak enhancement in that vessel. Scan delay for that patient is then determined by taking the t_{CMT} of the contrast and adding an additional small delay factor of a few seconds.

Bolus Triggering Method

This technique eliminates the test injection. The injection is begun, and the scanner obtains multiple images over an artery of interest (Figure 3.2). The t_{CMT} for the scan is determined automatically when the con-

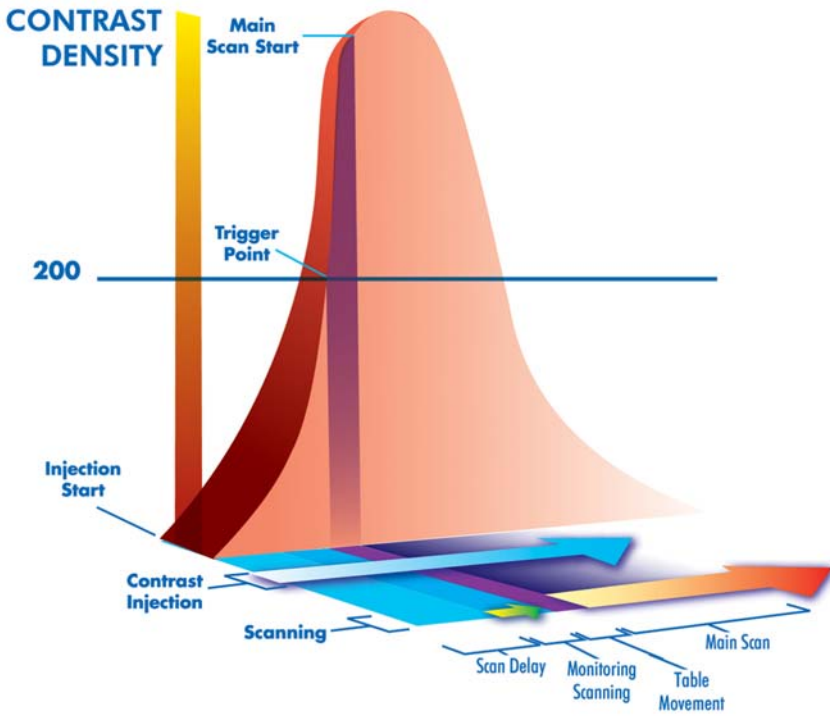

Figure 3.2. Illustration of the bolus triggering technique. Contrast injection is begun, and there is an initial scan delay until a monitoring scan begins. The monitoring scan tracks arterial density until the predetermined trigger point (200 HU) is reached. Once the trigger point is reached, there is a short delay to allow for table movement, and then the main scan begins. The scan and contrast injection proceed according to the preset parameters.

trast density in the artery exceeds a predetermined Hounsfield unit (HU) value (automatic triggering) or can be determined manually by the technologist based on the visual appearance of the contrast in the vessel (manual triggering). The scan will be initiated when either the predetermined HU or visual threshold is reached. There is an additional delay factor built into the test bolus method as it generally takes approximately 4 sec to 8 sec for the table to move and the scanning to begin once the triggering event has occurred.

Timing for most CTA examinations is fairly straightforward. A major vessel such as the aorta or pulmonary artery is selected to monitor the injection using either the test injection or bolus triggering method. The vessel chosen is important. It should be as large as possible if automatic triggering is used and either within or very close to the area of scanning interest. Smaller vessels can be chosen if manual visualization triggering is used.

One study where timing can be more difficult is the aortogram with runoff. Flow to the lower extremities can be asymmetric and highly variable. With current 16-slice scanners, it is possible to outrun the contrast bolus to the feet and end up with no contrast in the distal vessels. This can occur in the presence of significant arterial disease, and the problem is even more important with 32- and 64-detector scanners. It is also possible to over delay and end up with venous contamination. One trick is to use a slightly slower injection (3 mL/sec) and to trigger the scan from the common femoral artery in the groin rather than the aorta. Triggering on the femoral artery will account for the marked heterogeneity that can be seen in flow through the aorta and iliacs. On rare occasions, it is still possible to outrun the contrast with this technique, and a second run through the lower leg may be needed.

Scan timing for parenchymal organ studies of the abdomen is more forgiving than for CTA, but must still be done properly to be successful routinely. The standard fixed delay methods used traditionally for abdominal CT can still be used with MDCT with several modifications. Generally, all of the contrast should be in the patient before the scan is begun. A 70-sec delay for the abdomen and a 45- to 50-sec delay for the chest generally works well at a 2 mL/sec injection rate. At an injection rate of 3 mL/sec, the scan delays can be decreased by 10 sec to 15 sec for the abdomen and 5 sec to 10 sec for the chest, depending on injection duration (contrast volume). This can give a nice mix of vascular and organ enhancement.

Some studies, such as a dual-phase liver, require images in both the arterial and portal venous phase. The arterial portion of the scan can be triggered using an automatic method, but it is important to add at least 10 sec to 15 sec of additional delay onto the scan once contrast appears in the aorta. The goal is to image the liver in the late arterial phase, which usually occurs between 25 sec and 30 sec following injection at 4 mL/sec to 5 mL/sec or approximately 10 sec after dense contrast appears in the aorta. The second scan can be performed at 70 sec after the start of the injection. For a pancreatic study, an even longer delay is needed. The pancreatic phase occurs at approximately 40 sec or 20 sec to 25 sec after contrast first appears in the aorta.

Contrast Amount and Density

The amount of contrast used for a CT examination generally varies with the type of examination and often with patient factors. In choosing an effective amount and density of contrast, it is important to consider the main purpose of the contrast injection: Is it primarily for vascular (arterial) enhancement or for parenchymal organ or venous enhancement? To maximize arterial enhancement for vascular CTA studies, high-density contrast (≥350 mg I/mL) is recommended and should be paired with rapid injection rates of 4 mL/sec to 5 mL/sec. When high-density contrast is injected at a rapid rate, excellent arterial enhancement can be reliably achieved. Lower density contrast can be used, but then injection rates of 5 mL/sec to 6 mL/sec are needed to achieve the same degree of arterial contrast enhancement.

For CTA, the principal objective is to achieve and maintain optimal arterial enhancement throughout the scan. The length of the scan and the injection rate needed can determine the volume of contrast to be used. It is best to think in terms of flow rate and injection duration rather than contrast volume. A good rule of thumb to follow for MDCT is that the contrast injection time should last for the scan duration plus a small delay factor. The delay factor is generally between 4 sec and 10 sec and may correspond to the triggering delay seen with a bolus triggered scan between the triggering event and the initiation of scanning. This factor is, in effect, a contrast buffer to help insure that high-quality scans are consistently obtained and contrast enhancement does not fade out at the end of the study. When the bolus triggering method is used, the delay factor chosen can equal the expected time it takes the scanner to move the table and initiate scanning once the trigger threshold has been reached. It is possible to use the formula injection duration as the scan time without adding an additional delay. This reduces contrast dose, but for CTA, it leaves little room for error. This is just a basic guideline to be used as a starting point and is not meant to be followed precisely for all examinations without consideration of other variables.

$$\text{Injection Duration} = \text{Scan Duration} + \text{Delay Factor}$$

Scan duration for a study is provided at the scan console when the technologist plans the examination but can also be calculated with the following formula:

$$\text{Total Scan Time} = (\text{Total Distance Covered} \times \text{Rotation Time})/(\text{Pitch} \times \text{No. of Detector Rows} \times \text{Slice Thickness})$$

$$\text{Contrast Volume (mL)} = \text{Injection Duration} \times \text{Injection Rate (mL/sec)}$$

For example, to scan a thoracic and abdominal aorta (600-mm coverage) with a 16-detector scanner, 1-mm slices, rotation time of 0.5 sec, and a pitch value of 1.2, the scan would take approximately 15.6 sec. Scan duration + 5-sec delay factor = 20-sec contrast injection. At 4 mL/sec injection rate, a total of 80 mL would be needed, and at 5 mL/sec, 100 mL would be used. In patients who have low cardiac

output or in large patients, this amount should be increased, since it frequently takes longer to achieve adequate aortic enhancement. The minimum amount of contrast needed for CTA is approximately 75 mL for normal sized adults. Below this level, adequate vascular enhancement cannot always be obtained. Volumes can potentially be reduced even further if a saline flush is used. The maximum needed is usually 150 mL to 175 mL. Most examinations can be done with 75 mL to 125 mL of contrast.

For studies of the abdomen, it is very important to achieve good organ enhancement. Visualization of liver lesions can be difficult if adequate liver parenchymal enhancement is not obtained. There is a minimum amount of iodine needed to achieve this enhancement. At least 100 mL of 350 mg I/mL or 125 mL of 300 mg I/mL is suggested for good quality abdomen scans. This is the minimum requirement, and in fact, better visualization of lesions can be obtained by giving more contrast. When the liver is the target organ of the examination, increasing the amount of iodine used for the examination to at least 125 mL of 350 mg I/mL contrast is recommended. Timing and injection duration are less critical for venous or parenchmal studies than they are for CTA.

Injection Rate and Technique

Standard injection rates for CTA are 3 mL/sec to 6 mL/sec depending on the study performed. The faster the contrast is injected, the higher the peak aortic enhancement achievable. As described already, contrast density affects the peak enhancement possible, and less dense contrast needs to be injected faster to achieve the same enhancement level. Peak enhancement is also related to duration of injection. At a uniform injection rate, the aortic enhancement will continue to increase during the course of the injection.

Biphasic contrast injections can produce a more uniform plateau of contrast enhancement. This is achieved by injecting contrast at two different rates. The initial 25 mL of contrast is injected faster than the remainder of the contrast. A typical protocol for 350 mg I/mL contrast would be 30 mL at 5 mL/sec and 75 mL to 100 mL at 3.5 mL/sec. For 300 mg I/mL of contrast, the corresponding injection rates would be 6 mL/sec and 4 mL/sec.

Saline Flush

Dual head injectors are now becoming widely available. They offer the ability to inject a saline flush immediately following the contrast injections. Usually approximately 25 mL to 50 mL of saline is injected. Saline can also be used as a large-volume test bolus prior to contrast injection to, test the patient's IV line. This can help reduce the incidence of contrast extravasations.

Saline flush provides several benefits. It will clear the residual contrast from the IV tubing and accelerate washout from the arm veins. This can provide an effective 10 mL to 25 mL of additional usable con-

trast for CT examinations. This will improve organ enhancement and slightly prolong the vascular phase for angiography examinations. This benefit can effectively reduce the amount of contrast needed for both body CT examinations and CT angiography by approximately 25 mL. This will result in a cost savings and will potentially lessen the risk of contrast nephrotoxicity. Saline flush also reduces the very dense contrast seen in the subclavian vein, brachiocephalic vein, and superior vena cava (SVC). This helps reduce streak artifacts.

Pediatric Patients

Please refer to Appendix 1 for a discussion about administering contrast in children.

Selected Readings

1. Bae KT, Tran HQ, Heiken JP. Uniform vascular contrast enhancement and reduced contrast medium volume achieved by using exponentially decelerated contrast material injection method. Radiology 2004 Jun;231(3): 732–736.
2. Bae KT, Tran HQ, Heiken JP. Multiphasic injection method for uniform prolonged vascular enhancement at CT angiography: pharmacokinetic analysis and experimental porcine model. Radiology 2000 Sep;216(3):872–880.
3. Bae KT. Peak contrast enhancement in CT and MR angiography: when does it occur and why? Pharmacokinetic study in a porcine model. Radiology 2003 Jun;227(3):809–816.
4. Catalano C, Laghi A, Reitano I, Brillo R, Passariello R. Optimization of contrast agent administration in MSCT angiography. Acad Radiol 2002 Aug;9(suppl 2):S361–S363.
5. Choe YH, Phyun LH, Han BK. Biphasic and discontinuous injection of contrast material for thin-section helical CT angiography of the whole aorta and iliac arteries. Am J Roentgenol 2001 Feb;176:454–456.
6. Dorio PJ, Lee FT Jr., Henseler KP, et al. Using a saline chaser to decrease contrast media in abdominal CT. Am J Roentgenol 2003 Apr;180:929–934.
7. Eastwood JD, Lev MH, Provenzale JM. Perfusion CT with iodinated contrast material. Am J Roentgenol 2003;180:3–12.
8. Fleischmann D. Present and future trends in multiple detector-row CT applications: CT angiography. Eur J Radiol 2002;12(suppl):S11–S16.
9. Fleischmann D, Rubin GD, Bankier AA, Hittmair K. Improved uniformity of aortic enhancement with customized contrast medium injection protocols at CT angiography. Radiology 2000;214:363–371.
10. Fleischmann D. High-concentration contrast media in MDCT angiography: principles and rationale. Eur Radiol 2003 Nov;13(suppl 3):N39–N43.
11. Frush DP, Spencer EB, Donnelly LF, Zheng JY, DeLong DM, Bisset GS III. Optimizing contrast-enhanced abdominal CT in infants and children using bolus tracking. Am J Roentgenol 1999 Apr;172(4):1007–1013.
12. Haage P, Schmitz-Rode T, Hubner D, et al. Reduction of contrast material dose and artifacts by a saline flush using a double power injector in helical CT of the thorax. Am J Roentgenol 2000;174:1049–1053.
13. Herman S. Computed tomography contrast enhancement principles and the use of high-concentration contrast media. J Comput Assist Tomogr 2004 Jul–Aug;28(suppl 1):S7–S11.

14. Hopper KD, Mosher TJ, Kasales CJ, et al. Thoracic spiral CT: delivery of contrast material pushed with injectable saline solution in a power injector. Radiology 1997;205:269–271.
15. Hsu RM. Computed tomographic angiography: conceptual review of injection and acquisition parameters with a brief overview of rendering technique. Appl Radiol 2002;31(suppl):33–39.
16. Kirchner J, Kickuth R, Laufer U, et al. Optimized enhancement in helical CT: experiences with a real-time bolus tracking system in 628 patients. Clin Radiol 2000;55:368–373.
17. Luboldt W, Straub J, Seemann M, Helmberger T, Reiser M. Effective contrast use in CT angiography and dual-phase hepatic CT performed with a subsecond scanner. Invest Radiol 1999 Dec;34(12):751–760.
18. Luker GD, Siegel MJ, Bradley DA, Baty JD. Hepatic spiral CT in children: scan delay time-enhancement analysis. Pediatr Radiol 1996;26(5):337–340.
19. Mehnert F, Pereira PL, Trubenbach J, Kopp AF, Claussen CD. Biphasic spiral CT of the liver: automatic bolus tracking or time delay? Eur Radiol 2001;11(3):427–431.
20. Mehnert F, Pereira PL, Trubenbach J, Kopp AF, Claussen CD. Automatic bolus tracking in monophasic spiral CT of the liver: liver-to-lesion conspicuity. Eur Radiol 2001;11(4):580–584.
21. Napoli A, Fleischmann D, Chan FP, et al. Computed tomography angiography: state-of-the-art imaging using multidetector-row technology. J Comput Assist Tomogr 2004 Jul–Aug;28(suppl 1):S32–S45.
22. Ono S, Akaizawa T, Gotou R, et al. Analysis of time-density curves of contrast media for improvement of chest dynamic incremental CT. J Comput Assist Tomogr 1999 Sep–Oct;23(5):753–757.
23. Platt JF, Reige KA, Ellis JH. Aortic enhancement during abdominal CT angiography: correlation with test injections, flow rates, and patient demographics. Am J Roentgenol 1999 Jan;172:53–56.
24. Schoellnast H, Tillich M, Deutschmann HA, et al. Abdominal multidetector row computed tomography: reduction of cost and contrast material dose using saline flush. J Comput Assist Tomogr 2003 Nov–Dec; 27(6):847–853.
25. Tublin ME, Tessler FN, Cheng SL, Peters TL, McGovern PC. Effect of injection rate of contrast medium on pancreatic and hepatic helical CT. Radiology 1999 Jan;210(1):97–101.
26. van Hoe L, Marchal G, Baert AL, Gryspeerdt S, Mertens L. Determination of scan delay time in spiral CT-angiography: utility of a test bolus injection. J Comput Assist Tomogr 1995;19:216–220.