

CONTRAST MEDIA APPLICATIONS IN MDCT

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In general, optimized contrast injection is an important issue to achieve high quality computed tomography (CT) scans with homogeneous attenuation and high contrast throughout the entire data set. CT angiography (CTA) in particular will benefit from homogeneous and compact bolus geometry. Multidetector-row spiral CT (MDCT) has substantially improved over the past years with faster gantry rotation, more powerful X-ray tubes and dedicated interpolation algorithms. As one of the consequences of this technical evolution, CTA has become an established technique for minimally invasive vascular imaging. Together with magnetic resonance angiography (MRA), MDCT replaced a significant number of diagnostic catheter angiographies. When compared with magnetic resonance imaging, MDCT is considered advantageous with respect to therapeutic confidence and costs for the initial evaluation. Fundamental advantages of the new MDCT scanners are provided by three cornerstones, i.e. shorter scan time, larger scan range and improved spatial resolution.

MDCT with 16- and more slices permits imaging of the entire aorta during a single breathhold. The scan volume easily covers the whole body at sub-millimeter resolution. Advanced scanning techniques such as dual-energy applications using dual-source CT technique simplify time-consuming post-processing; as bone-removal algorithms are more robust due to the different energy spectra of iodine and bony structures. Ideal intravascular contrast, however, forms the basis for advanced 3D post-processing such as volume-rendering technique. This may enable optimal analysis of the data set without venous contamination, another prerequisite for successful post-processing.

Scanning parameters

The main trade-off that has to be resolved in CTA is to do the splits between spatial resolution and z-coverage. At a given slice thickness, an increase in scan speed and volume coverage of up to a factor of eight has already been achieved using 4-slice platforms with 0.5 s gantry rotation time. With 16-slice, 32-slice, 40-slice, 64-slice and even 256-slice and 320-slice MDCT technology as well as a further increase of gantry rotation speed, these degrees of freedom become more evident, as true sub-millimeter resolution is available on a routine basis (0.4-0.75 mm).

With single-slice CT, tube power as well as breathhold time for the patient were the main restrictions in clinical routine. For example, examinations of the thoracic and abdominal aorta usually had to be split into two separate exams, even with sub-second rotation time (0.75 s). A single breathhold of 30 s was mandatory to cover a 30 cm section along the patient axis at a given slice collimation of 5 mm with a pitch of 1.5 (table feed / rotation: 7.5 mm).

Already for 4-slice systems an improved contrast material efficiency is seen, mainly due to the aggregation of two separate examination procedures (reduction of the overall contrast volume at comparable Hounsfield units [HU]).

With 64-slice MDCT scanners, the scan time can be cut down to 12 s, using 0.6 mm collimated protocols at a rotation time of 0.33 s for scanning the entire chest and abdomen (~80 cm z-coverage).

For cardiac imaging, the latest 320-slice MDCT system allow for full anatomical 16 cm coverage within a single rotation (at 0.5 mm detector elements). A different approach will be offered by the second generation dual-source technology: Using high-pitch protocols (up to 3.4 for cardiac imaging and 3.2 for chest applications), an electrocardiography-triggered spiral coverage of the entire heart and the chest is technically feasible with less than 1 s scan time.

Contrast medium administration

High and constant iodine contrast should be maintained throughout the whole data set to achieve an optimal opacification and therefore optimal contrast between the vessel lumen and the surrounding soft tissue. Today's fast data acquisition allows optimization of enhancement profiles and dedicated examinations of entire organs in several predefined contrast phases (e.g. late-arterial phase of the liver, cortico-medullary phase of the kidney). Also, first-pass perfusion imaging becomes technically feasible and more and more part of clinical routine. Current applications include the CT assessment of cerebral malperfusion or characterization of dedicated lesions. Future indications may include the early assessment of therapy response in cancer.

Sophisticated injection protocols have been advocated and incorporated into the clinical work-up, e.g. biphasic injections for coronary CT applications. However, many complex multiphasic contrast delivery protocols for ideal contrast enhancement are still based on dedicated mathematical equations and have not yet undergone sufficient clinical evaluation. Therefore, monophasic contrast medium injection in conjunction with a saline chaser bolus is still standard for routine CTA studies in most centers.

Numerous factors affect the geometry of the contrast media bolus in CTA. These factors may be divided into intrinsic patient related factors and extrinsic contrast material and injection technique associated parameters, and include

- + Patient cardiac output, individual pathology, specific parameters

(e.g. body-mass-index, blood pressure, heart rate, and gender)

- + Specific pharmacologic features of the contrast material itself

(e.g. iodine concentration, viscosity, temperature, as well as physiologic effects of the contrast medium injected)

- + Injection technique

(e.g. flow rate, total iodine volume, mono-, bi-, or multiphasic injection, as well as use of saline chaser)

The overall **iodine load** is the key determinant for the imaging of solid organs. In general, shorter acquisition times may to some extent reduce the total amount of contrast material needed. The overall amount of contrast material administered to the patient for CTA studies, however, is of minor importance: Injection duration and particularly the **iodine delivery rate** (IDR, given in g iodine/s) are the determining factors for the quality of the bolus. The latter can easily be calculated by multiplying the iodine concentration of the contrast material (g iodine/mL) with the flow rate of the injector (mL/s). Usually the IDR will be in the range of 1.5-2.0 g iodine/s for CTA applications. This can be realized by using a high-concentration contrast medium (350-400 mg iodine) in combination with moderate flow rates. On the other hand, the same IDR can also be achieved by increasing the flow rates, e.g. for contrast material with 300 mg of iodine per mL. Normalizing the IDR is a straightforward means of making different injection protocols comparable.

It seems obvious that the choice of a contrast agent with a high iodine concentration permits the use of lower flow rates when compared with a lower iodine concentration. This may help to avoid local complications such as paravasation. It should be kept in mind that the relation between the iodine concentration of a contrast medium and its viscosity is exponential. This means that the pressure that is built up by the power injector and the resulting pressures at the site of injection and subsequently inside the patient's veins might be even higher with highly concentrated agents despite the fact that they are injected at slower flow rates. The clinical effect of different flow rates and contrast medium viscosities on the incidence of paravasation is not fully understood and requires prospective large population studies. However, the benefit of large access lines (e.g., 18G needles) and of pre-heating the contrast material to a mean body temperature of 37°C in order to bring down the viscosity is obvious. The latest proposals for advanced CTA scanning favor weight-adjusted iodine dose protocols at a given IDR, e.g. for examinations of the coronary arteries. At optimal HU values, a cumulative saving of approximately ¼ of the overall contrast material is achievable compared with a fixed iodine dose at a given IDR.

Nowadays, combined examination protocols are often performed, e.g. including an arterial phase for assessing the arterial anatomy as well as for the depiction of hypervascular lesions within solid organs followed by additional venous phase scanning of the entire abdomen. Hence, to achieve optimal results, the contrast media delivery has to address both issues: For the initial series, the IDR will be the major determinant, while the overall iodine load is essential for the quality of the portal-venous phase. The iodine load is usually fixed for a dedicated scan protocol, or adapted to the patient's total body weight. For liver imaging, an individual estimation of the iodine load based on the body weight of the patient (521 mg iodine / kg body weight) has been advocated. Solid organs, however, are perfused with proportionally more blood – and therefore more contrast medium – than adipose tissue. Thus, a calculation of contrast medium dose for CT imaging on the basis of lean body weight (exclusive of adipose tissue) might also result in more consistent solid organ enhancement.

In any case, empiric scan delays can no longer be recommended using MDCT. With 16 or more slice MDCT scanners, the start delay of a CTA has to be chosen individually. Human physiology with short time frames for dedicated vessel and contrast phase analyses require dedicated contrast regimes e.g., CTA of the hepatic arteries and the late arterial hepatic phase for the detection of hypervascularized liver lesions, respectively. In the clinical setting, two modes are currently available for optimal enhancement after intravenous contrast delivery: the scan delay can be determined individually by acquisition of single-level dynamic CT series (automated bolus tracking). A pre-monitoring scan is performed within the target volume to localize the target vessel for contrast timing. A low-dose scanning technique (e.g. 120 kVp; 20 mAs_{eff.}) is usually used for this purpose. A region-of-interest (ROI) is placed in the target vessel and attenuation values (in HU) are measured every two seconds during the contrast injection. When the predefined trigger threshold level is reached (e.g. 140 HU), an automated start of the CT scan is initialized.

Here, the additional transition delay has to be considered, defined as the delay after the threshold is reached and the start of the actual CT scan; usually ranging between 5-15 s, respectively.

Alternatively, a test-bolus methodology can be used. This approach requires the injection of a small additional volume of contrast material (usually 15-20 mL) in order to define the circulation time, using the same flow rates as used for the final contrast enhanced scan protocol. By repeat acquisition of serial scans (monitoring scans every 1-2 s for ~10-40 s; usually at the level of the heart), individual flow dynamics can be assessed more precisely: Time-to-peak enhancement can be calculated from the enhancement over time within the target vessel lumen. The latter will be chosen as start delay. Test-bolus data also allows estimation of the bolus geometry with a given amount of contrast medium at a selected flow rate. Moreover, this technique allows individual tailoring of the contrast medium injection. It is a prerequisite for an individualized bolus design constituting a more specific approach to the injection regimen as compared to automated bolus tracking. Finally, this technique permits the determination of cardiac output from the contrast enhancement curve and therefore gives insight into the cardiovascular status of the patient.

The use of double-power injectors has been advocated for automated saline-flushing at the injection site, especially for CTA examinations. Otherwise, ~20-30 mL of contrast material are retained in the "dead space" between the brachial vein and the superior vena cava. Consequently, performing saline flush improves arterial enhancement and reduces the amount of contrast needed for a diagnostic examination. In the long run, using a double-power injector will positively affect patient safety and costs.

Previously unknown problems can occur with the latest and fastest scanning techniques: The contrast bolus might be overrun by the CT scanner, if contrast delivery and scan protocol are not adjusted properly. From a clinical perspective, the paradigm of ever increasing scanning speed is contradicted by practical needs. In patients with co-existing cardiovascular disorders the pitch values of these scanners sometimes have to be lowered to slow down the examination speed in order to avoid outrunning the contrast bolus, especially in long distance CTA for the entire aorta and peripheral run-off studies.

An examination strategy can be planned on the basis of an estimation of the individual patient's circulation time (= contrast transit time). Hence, two different test boluses and dynamic series in the upper and lower portion of the volume

data set are recommended to derive this information individually. Contrast transit time can be calculated by subtracting the time-to-peak enhancement of the proximal measurement from the time-to-peak enhancement of the distal measurement. Using the distance in the z-direction between the two test boluses, intravascular contrast transit can be calculated in millimeter per second. Thereafter, the table feed per rotation can be adapted accordingly.

In summary, optimal contrast bolus shaping with special emphasis on bolus design and timing is a key issue in modern MDCT imaging, especially for arterial phase imaging. The IDR is the most important factor for achieving this goal and can be optimized by adapting the flow rate of the injector to the iodine concentration of the chosen contrast medium. Test-bolus methodology and automated bolus tracking are routine techniques for individual optimization of the contrast enhancement and help to increase the robustness of this examination method.

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