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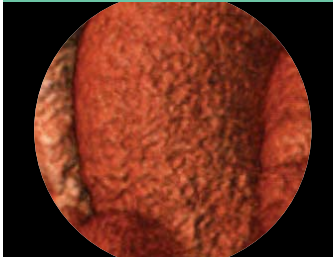
# Contrast medium injection protocols for CT angiography

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### Introduction

As part of a general trend towards non-invasive imaging techniques, the use of CT and MRI is increasing while the use of other radiological investigations is constant or is in decline.<sup>1</sup> In line with this, CT angiography (CTA) is gradually replacing conventional diagnostic angiography. At the same time, there is increasing use of CT in more vulnerable populations such as the elderly and patients with comorbidities.<sup>2</sup>

With the latest multichannel CT scanners, scan times have been greatly reduced. For example, CTA of the abdominal aorta with 64-channel CT currently takes 5 seconds or less, in comparison with 40 seconds that a single detector machine took in 1998. This has profound implications for the way that contrast medium needs to be injected. In order to maximise the benefits of the latest CT scanners, the injection protocols need to be optimized to guarantee strong arterial opacification and thus take full advantage of the new technical capabilities.

Since the latest 40- to 64-channel scanners virtually eliminate the technical trade-offs of spatial resolution *versus* volume coverage, this allows a new approach with regard to how injection protocols and scanning protocols can be designed. At the same time, it has become apparent that it is not necessary to use the latest scanners at their maximum speed – this can in fact be detrimental. Therefore, we currently observe a paradigm shift towards designing individualised 'physiological' injection protocols that subsequently determine the appropriate scanning protocol.

The design of injection protocols requires users to not only be aware of the pharmacokinetic and physiological parameters that determine arterial enhancement, but also to be aware of the role of user-selected parameters such as injection rate, duration and iodine content. A central principle – which should be adopted for easier understanding of the arterial contrast medium dynamic in general – is to consider a contrast medium injection

protocol for CTA as a combination of the contrast medium injection rate (rate of iodine administration; mg iodine/sec) and the injection duration (rather than the volume).

### Pharmacokinetic principles

Iodinated contrast media are rapidly distributed throughout the intra- and extravascular extracellular space following intravenous administration. Early vascular enhancement depends on the rate of iodine administration and the blood flow, whereas parenchymal enhancement depends on the total iodine dose and the volume of distribution.

The time interval required for an intravenously injected bolus of contrast medium to travel to the arterial site of interest is usually referred to as the contrast medium transit time ( $t_{CMT}$ ). The first peak of arterial enhancement reflects the first-pass effect, while the tail of the enhancement curve from a small test-bolus injection is due to bolus broadening and recirculation, as shown in Figure 1 (for an injection of 16 ml at 4 ml per second). Increasing the injection rate from 4 ml/s to 8 ml/s (thus increasing the iodine administration rate to 2.4 g/second, using a contrast medium containing 300 mg iodine/ml) increases the enhancement proportionally, by a factor of two, as shown in Figure 2. When the contrast medium is given over a longer period, for example 32 seconds, the observed enhancement can be regarded as the sum of a number of shorter boluses, each of which has a first pass

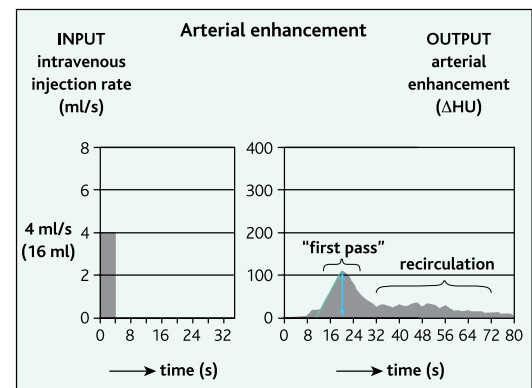


Figure 1. Arterial enhancement achieved with intravenous injection of 16 ml of iodinated contrast medium at 4 ml/second (1.2 g iodine/second).

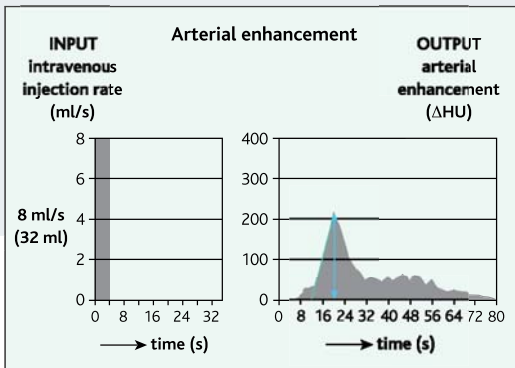
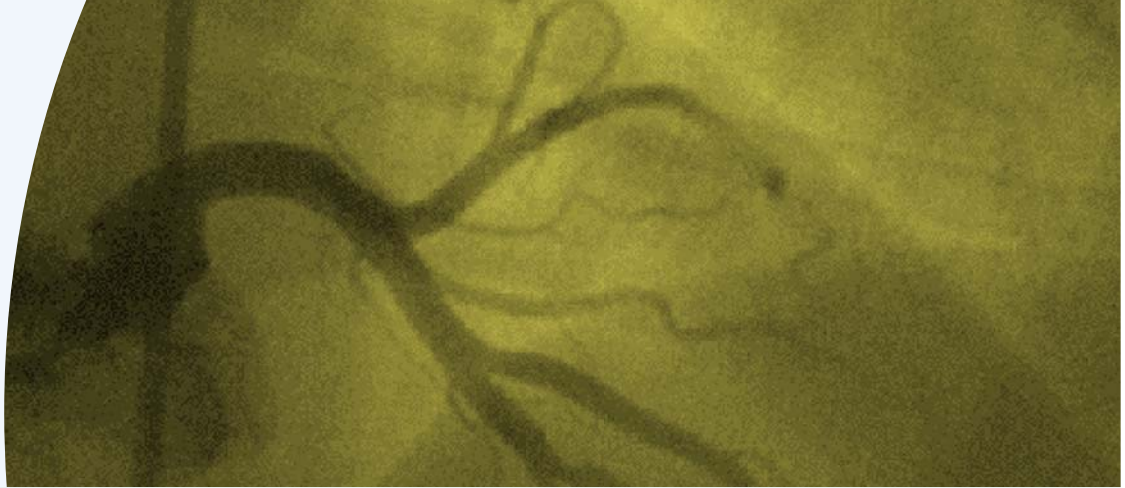


Figure 2. Arterial enhancement achieved with intravenous injection of 32 ml of iodinated contrast medium at 8 ml/second (2.4 g iodine/second).

rate. However, there is considerable variation between individuals with respect to the degree and time course of vascular enhancement. The most important patient factors influencing enhancement are cardiac output and central blood volume, which are both correlated with body weight. There is an inverse relationship between cardiac output and arterial enhancement; although the  $t_{CMT}$  is increased in patients with a low cardiac output, the overall effect is stronger enhancement. The relationship between central blood volume and individual arterial enhancement is also an inverse one, presumably associated with recirculation and tissue enhancement, rather than a first-pass effect.

and a re-distribution effect (Figure 3).<sup>4</sup> Thus, over a longer period, the cumulative effect of these '8 subsequent test-boluses' on arterial enhancement is a gradually increase followed by a rapid decrease.

#### Patient factors

For a given individual and vascular territory, the enhancement is proportional to the iodine injection

#### 'Key rules' of early arterial contrast medium dynamics

The design of injection protocols is facilitated by using the three 'key rules' that determine early arterial enhancement in the time frame relevant for CT angiography:

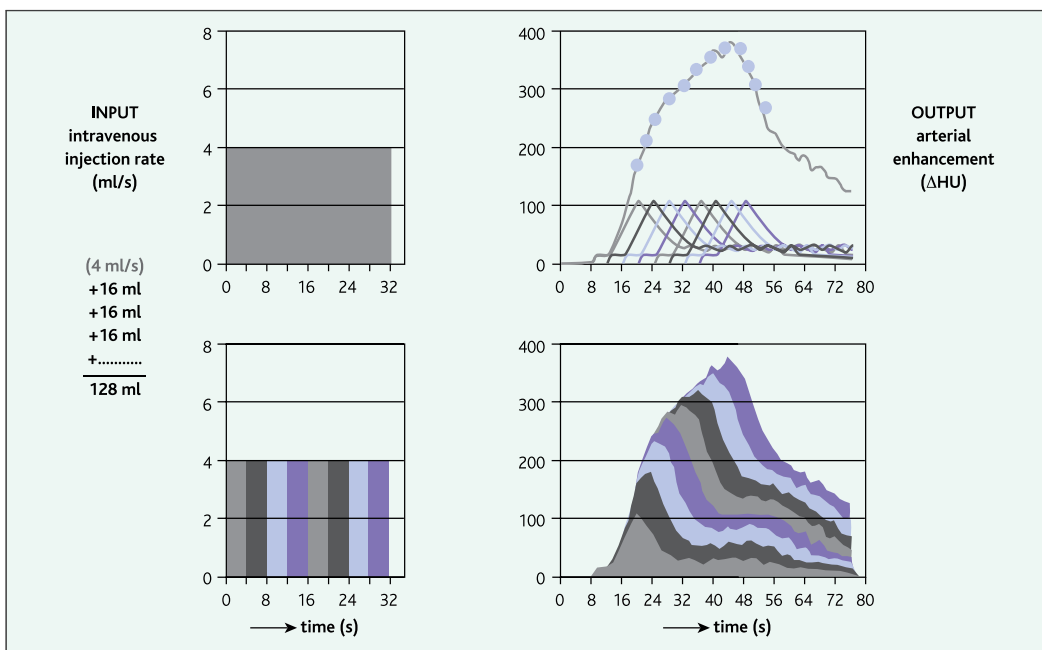
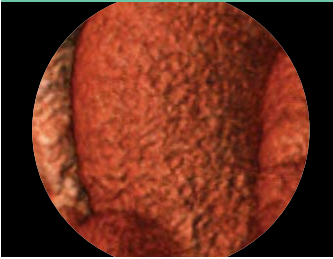


Figure 3. Arterial enhancement achieved with a 32-second injection of 128 ml of iodinated contrast medium at 4 ml/second (1.2 g iodine/second).

# Contrast medium injection protocols for CT angiography *continued*

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## 1. Arterial enhancement is proportional to the iodine administration rate

Vascular enhancement is directly proportional to the number of iodine molecules administered per unit of time and can be increased by increasing the iodine concentration of the contrast medium (mg iodine/ml) and/or the injection rate (ml/sec) (Figure 4).

## 2. Arterial enhancement increases with longer injection duration

A longer injection duration also results in stronger enhancement. This effect is not directly proportional, but it is a 'cumulative' effect as shown in Figure 5.

## 3. The injection rate and contrast volume should be adjusted according to the patient's weight

## Injection protocols

Injection protocols for CTA are generally designed to match the scan time. In the past, the scan times were determined by the scanner capabilities. Using traditional CTA injection protocols – derived in the era of single slice CT – it was usual to try to scan a given vascular territory as fast as possible. The general principle was to select an injection duration equal to the scan time. For example, one would inject for 30 seconds to achieve good arterial opacification for a 30s CTA acquisition. Shorter acquisition times – which became possible with multichannel CT systems – have some definite advantages (namely reduced breath-hold times, reduced patient movement, and use of lower volumes of contrast medium). When scan times and injection durations become shorter, the injection rates need to be increased to compensate for the shorter time allowed to build up arterial enhancement. Even shorter scan times – which

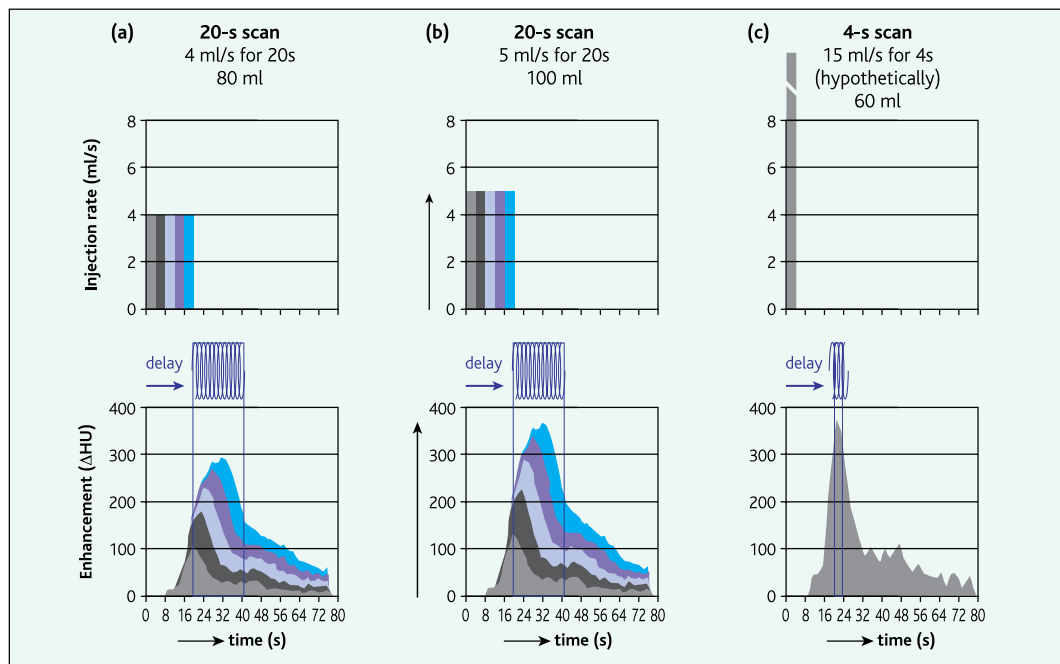


Figure 4. Effect of increasing the injection rate. Arterial enhancement achieved with: (a) intravenous injection of 80 ml of contrast medium at 4 ml/second for 20 seconds and a 20 second scan time (20 second delay); (b) intravenous injection of 100 ml of contrast medium at 5 ml/second for 20 seconds and a 20 second scan time (20 second delay); (c) hypothetical intravenous injection of 60 ml of contrast medium at an impractical 15 ml/second for 4 seconds and a 4 second scan time (20 second delay).

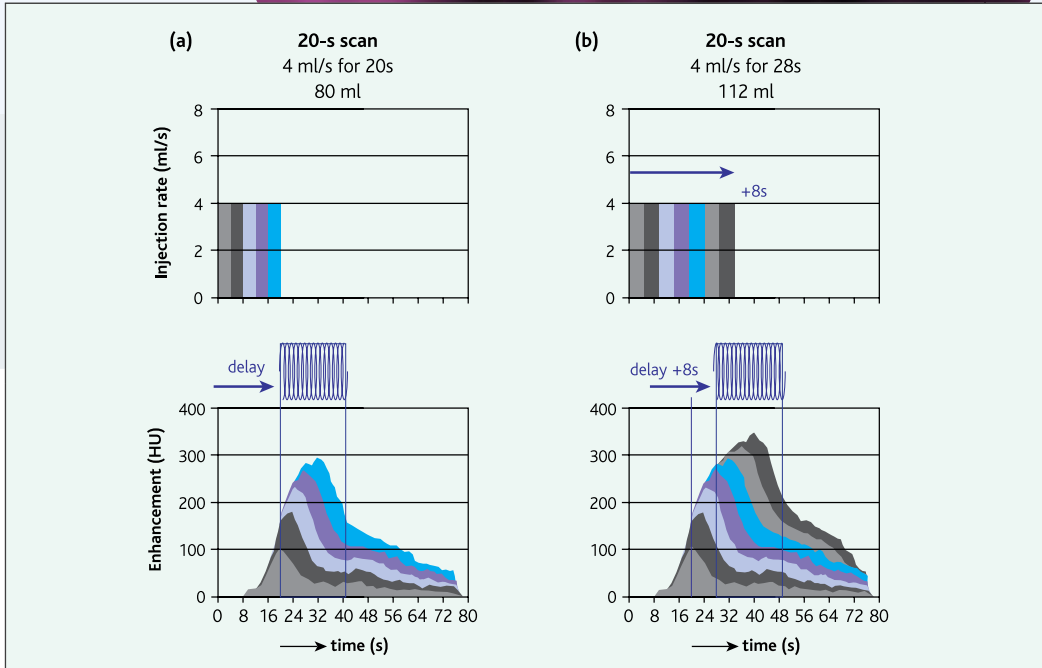


Figure 5. Effect of increasing the injection duration and the delay. Arterial enhancement achieved with: (a) intravenous injection of 80 ml of contrast medium at 4 ml/second for 20 seconds and a 20 second scan time (20 second delay); (b) intravenous injection of 112 ml of contrast medium at 4 ml/second for 28 seconds and a 20 second scan time (28 second delay).

have become possible with current 64-channel scanners – are not necessarily an additional advantage.

Very short scan times (in the range of 5s or less) are in fact associated with significant disadvantages:

1. Lower enhancement
2. Delayed and insufficient opacification of large aneurysms, and
3. The risk of outrunning the bolus (e.g. in patients with peripheral arterial disease) or missing it completely.<sup>3</sup>

With faster scanning times, synchronizing CT acquisition with the desired phase of enhancement becomes even more critical.

So how should injection protocols be designed for different vascular territories with different acquisition times and different scanners? How can injection protocols also account for the considerable variation between individuals with respect to the degree and time course of vascular enhancement? The apparent solution is not to design the injection protocol based on

the scanner capabilities, but based on the physiology of arterial enhancement. Since new 64-channel scanners allow a very flexible selection of scan-times, one should select the scan time that best matches arterial enhancement – not the 'traditional' other way around.

An example of our current 64-channel abdominal CTA scanning and injection protocol is shown in Figure 6. Note, that the scan time is 10s in all patients. This is much slower than one could scan with this machine, and is achieved by using a variable, small pitch. Automated tube current modulation is used to control radiation exposure and image noise. A reliable, strong arterial enhancement is achieved by using the same injection duration of 18s in all subjects. We use an automated bolus triggering technique to time the CT acquisition such that the scan is initiated 8s after the contrast medium has arrived in the aorta  $t_{\text{CMT}} + 8\text{s}$ . This enables a good build-up of arterial opacification and also allows aneurysms (if present) time to opacify. Since the injection duration is equal across patients, it is finally possible to simply adjust the injection rates (and volumes) to patient weight.

# Contrast medium injection protocols for CT angiography *continued*

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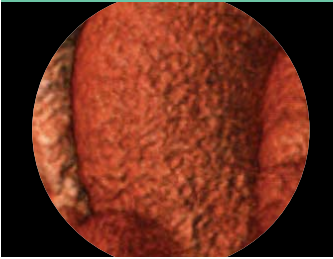


Figure 6. Examples of contrast medium injection protocols for CT angiography of the aorta, adjusted for bodyweight.

Integrated 64-channel MDCT acquisition and injection protocol for abdominal CTA			
Acquisition	64 x 0.6 mm (number of channels x channel width); automated tube current modulation (250 quality reference mAs)		
Pitch	Variable (depends on volume coverage, usually <1.0)		
Scan time	Fixed to 10 seconds (in all patients)		
Injection duration	Fixed to 18 seconds (in all patients)		
Scanning delay	$t_{\text{CMT}}+8\text{s}$ (scan starts 8 seconds after CM arrives in the aorta, as established with automated bolus triggering)		
Contrast medium	High concentration ( $\geq 350$ mgI/ml), or isosmolar (320 mgI/ml), followed by saline flush		
Injection flow rates and volumes	Individualised to body weight		
	Body weight	CM Flow rate	CM Volume
	<55 kg	4.0 ml/s	72 ml
	56–65 kg	4.5 ml/s	81 ml
	66–85 kg	5.0 ml/s	90 ml
	86–95 kg	5.5 ml/s	99 ml
>95 kg	6.0 ml/s	108 ml	

## Key Learning

- Arterial enhancement is proportional to the iodine administration rate, which is determined by the iodine concentration of the contrast medium and the rate of injection
- A longer injection and increased delay result in stronger enhancement
- Injection protocols need to be customised including adjustment of the injection rate and volume according to the patient's weight

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