

Myocardial Perfusion Imaging with ^{201}Tl *

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The object of this review is to provide information about ^{201}Tl -thallous chloride in radionuclide myocardial perfusion imaging. This technique has experienced a recent resurgence because of the shortage of $^{99\text{m}}\text{Tc}$. After reading this article, the technologist will be able to describe the properties and uptake mechanism of ^{201}Tl , the procedure for myocardial perfusion imaging with this agent, and the advantages and disadvantages of thallium, compared with the technetium agents.

Key Words: myocardial perfusion; ^{201}Tl -thallous chloride; SPECT; $^{99\text{m}}\text{Tc}$ -sestamibi; $^{99\text{m}}\text{Tc}$ -tetrofosmin

J Nucl Med Technol 2010; 38:1–3

DOI: 10.2967/jnmt.109.068593

The use of ^{201}Tl -thallous chloride for myocardial perfusion imaging is well documented. In fact, ^{201}Tl -thallous chloride established the foundation for myocardial perfusion imaging in the 1970s (1). Although the newer technetium-labeled agents generally produce slightly better image quality, there are advantages to thallium such as higher first-pass extraction and the ability to keep up with blood flows at higher rates and with larger defect sizes at stress (2). Because of the shutdown of various molybdenum-producing reactors worldwide, we are due to experience an extremely short supply of $^{99\text{m}}\text{Tc}$ in the next year. ^{201}Tl is a cyclotron-produced isotope and widely available. Unlike many general nuclear medicine procedures routinely performed with $^{99\text{m}}\text{Tc}$ -labeled tracers, radionuclide myocardial perfusion imaging has a reputable alternative. After reading this article, the technologist will be able to describe the properties and uptake mechanism of ^{201}Tl , the procedure for myocardial perfusion imaging with this agent, and the advantages and disadvantages of thallium, compared with the technetium agents.

THALLIUM PROPERTIES, UPTAKE, AND DISTRIBUTION

^{201}Tl decays by electron capture to ^{201}Hg , which emits x-rays primarily at 68–80 keV but also γ -rays (3) at 137 and 167 keV with a mean percentage per disintegration of 94.5%, 3%, and 10%, respectively (4). ^{201}Tl has a half-life of 73.1 h. Thallium is transported across the myocyte membrane by the $\text{Na}^+ \text{K}^+$ adenosine triphosphatase transport system and by facilitative diffusion (5). The first-pass extraction is about 85%, which is higher than the $^{99\text{m}}\text{Tc}$ -labeled myocardial perfusion imaging tracers. ^{201}Tl also has less “roll-off” than the currently available $^{99\text{m}}\text{Tc}$ tracers and is therefore able to keep up with higher coronary flow rates and may be able to better detect coronary artery stenosis between 50% and 70% (6). The percentage uptake of the injected dose in the myocardium is also higher than for the $^{99\text{m}}\text{Tc}$ tracers, 3%–4% for ^{201}Tl versus 1.0%–1.4% for the $^{99\text{m}}\text{Tc}$ tracers (7). The myocardial concentration peaks within 5 min after injection and at that time is representative of myocardial blood flow (5). The redistribution process begins within 10–15 min after injection. The tracer clears more rapidly from normal myocardium than from abnormal myocardium. As underperfused but viable myocardium retains the thallium while it washes out of normal areas, initial defects appear to normalize. This redistribution property makes ^{201}Tl superior to the $^{99\text{m}}\text{Tc}$ -labeled myocardial perfusion agents for viability assessment. Imaging performed shortly after a rest injection of ^{201}Tl is a pattern representing resting myocardial blood flow. Delay images of 4 or preferably 24 h represent a viability assessment. In the case of hibernating myocardium, immediate images will show decreased tracer activity; however, this area would be reversible on delayed images. Because ^{201}Tl is cleared by the kidneys, there is usually not a significant amount of hepatobiliary activity as with the $^{99\text{m}}\text{Tc}$ -labeled tracers. Because of the longer half-life of this agent, the whole-body radiation dose is significantly higher per megabecquerel injected than for the technetium agents (3.6×10^{-1} vs. 8.61×10^{-3} mSv/MBq) (8,9).

THALLIUM PROTOCOLS

The protocol used for so many years before the introduction of the $^{99\text{m}}\text{Tc}$ -labeled myocardial perfusion imaging tracers is a stress/redistribution ^{201}Tl protocol. It is standard to use low-energy general-purpose collimators for this protocol; however, the use of low-energy high-resolution collimators is certainly an alternative. The protocol presents a logistic challenge. The protocol is to inject 111–148 MBq

Received Jul. 20, 2009; revision accepted Dec. 2, 2009.
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(3–4 mCi) of ^{201}Tl intravenously at peak stress and to continue exercise for 1 min after injection. A γ -camera must be available immediately after the stress test. Because of the redistribution properties of ^{201}Tl , the patient imaging must begin within 10–15 min after stress, but a delay of at least 10 min is required because imaging sooner can potentially cause an upward-creep artifact that can lead to false-positive findings (10). As with $^{99\text{m}}\text{Tc}$ -labeled agents, pharmacologic stress with either chronotropic or vasodilating agents may be performed, but unlike the $^{99\text{m}}\text{Tc}$ -labeled agents, imaging must begin shortly after the pharmacologic stress. Time per projection by guidelines is 40 s (for 32 projections) or 25 s (for 64 projections), but further increasing imaging time will greatly improve image quality. Two energy windows are used, one at 70 keV (25%–30% window) and another at 167 keV (20%). A 180° orbit with 32–64 projections is standard (11). Gating of ^{201}Tl images has been shown to be accurate (12), even in the presence of large perfusion defects (13). If the study is count-poor, 8 frames per cycle are recommended as an alternative to 16 frames per cycle, to double the counts per frame. The patient then returns for 4- or 24-h redistribution imaging using the same imaging parameters. It is preferred that patients take nothing by mouth if returning for 4-h redistribution images. An active stomach muscle will result in increased thallium uptake, which can preclude adequate image interpretation. One exception is the additional scan time recommended for 24-h imaging.

An alternative to this standard stress/redistribution protocol is a stress/reinjection protocol. Typically, 111 MBq (3 mCi) of ^{201}Tl are injected at stress, immediately followed by imaging. The patient is then reinjected with 55.5 MBq (1.5 mCi) and returns in 4 h for imaging. This protocol may reduce the number of times the patient needs to be scanned, but in patients with fixed defects, a 24-h scan may still be indicated. In either protocol, if the initial stress images have normal findings, there is no need for further imaging.

If a $^{99\text{m}}\text{Tc}$ supply is available, a dual-isotope protocol may be used (14). The protocol will allow for a significant reduction in the amount of the $^{99\text{m}}\text{Tc}$ used, compared with a $^{99\text{m}}\text{Tc}/^{99\text{m}}\text{Tc}$ protocol. This protocol is efficient because the delay between rest injection and imaging is minimized, no delay is necessary for decay between rest and stress, and if an exercise stress method is performed, stress $^{99\text{m}}\text{Tc}$ images can begin 10–15 min after injection.

For this protocol, a 111- to 148-MBq (3- to 4-mCi) (0.04 mCi/kg [1.48 MBq/kg]) ^{201}Tl dose is used, followed by 740–1,110 MBq (20–30 mCi) of a $^{99\text{m}}\text{Tc}$ -labeled myocardial perfusion imaging tracer. Instead of waiting 30–60 min after the rest injection as is standard with $^{99\text{m}}\text{Tc}$ -labeled myocardial perfusion tracers, one waits only the 10–15 min that is considered adequate after a ^{201}Tl rest injection. It is standard to scan with low-energy high-resolution collimators for ^{201}Tl imaging as part of a dual-isotope protocol. Additional parameters for the rest ^{201}Tl portion of the dual-isotope procedure for a dual-head system are described

above. Patients with fixed defects on the dual-isotope protocol should have an additional 24-h redistribution scan (15).

PROCESSING

Processing of ^{201}Tl images is generally more straightforward than that of $^{99\text{m}}\text{Tc}$ -labeled myocardial perfusion tracers because of the absence of significant hepatobiliary activity. Generally, there are lower count statistics for ^{201}Tl images than for $^{99\text{m}}\text{Tc}$ -labeled myocardial perfusion tracers, resulting in an inferior signal-to-noise ratio. As a result, more filtering is necessary for the ^{201}Tl images. As is the case with filtering any type of myocardial perfusion imaging study, the technologist and interpreting physician should begin with manufacturer recommendations and slightly adjust the filter to the physician's preference. These filter parameters should then be used on all ^{201}Tl studies. Filters should not be adjusted for each individual study because they will potentially affect sensitivity, specificity, ventricular volumes, ejection fraction, and perfusion quantitation.

INTERPRETATION

There is significantly less hepatobiliary activity with ^{201}Tl myocardial perfusion studies than with studies performed using $^{99\text{m}}\text{Tc}$ -labeled myocardial perfusion tracers. This is, of course, a favorable trait when interpreting studies. The ^{201}Tl studies present challenges of their own, mostly related to count density. The long half-life of ^{201}Tl limits the dose that can be administered while keeping patient radiation exposure within acceptable limits. Because of the short duration between stress and imaging, an artifact due to upward creep is possible. A difference in cavity size is often present when a dual-isotope protocol is used. Because of the lower resolution, increased filtering, and therefore blurring, the thallium images will result in a smaller left ventricular cavity. It is not until the stress-to-rest ratio is greater than 1.22 that transient ischemic dilatation is present (16). An increased lung-to-heart ratio is associated with increased cardiac events even in the absence of myocardial perfusion defects (17).

CONCLUSION

Thallium was the first widely available radiopharmaceutical for myocardial perfusion scans. Since the late 1970s, ^{201}Tl was used with planar imaging to detect coronary artery disease. In the 1980s, ^{201}Tl was the most common radiopharmaceutical used in SPECT myocardial perfusion imaging (18). Most technologists and physicians with nuclear cardiology experience dating back to the 1980s have considerable experience with ^{201}Tl myocardial perfusion imaging. ^{201}Tl has several advantages over the current $^{99\text{m}}\text{Tc}$ myocardial perfusion agents, including a higher first-pass extraction and a higher roll-off translating to larger defects and sensitivity in showing defects in 50%–70% stenoses. The dual-isotope, redistribution, and reinjection

protocols all offer efficiencies. Radiation burden, counting rates, and delayed imaging present challenges. Unquestionably, myocardial perfusion imaging can persevere without ^{99m}Tc .

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