Radiography with Gadolinium Contrast Agents

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22.1 Introduction

At the kV (~70) used for digital angiography, the attenuation of X-rays by gadolinium is approximately the same as for iodine and at the kV (~120) used for CT, the attenuation of X-rays by gadolinium is approximately double that of iodine, so theoretically gadolinium could therefore replace iodine as a radiographic contrast agent.

It has been suggested that patients with significant renal impairment and/or previous severe reactions to iodinated contrast media should receive gadolinium-based MRI contrast agents instead of the traditional iodinated radiographic contrast agents (Albrecht and Dawson 2000; Bittner et al. 1997; Engelbrecht et al. 1996). Another possible indication suggested for using gadolinium based contrast agents rather than iodinated agents is before thyroid treatment with radioactive iodine to avoid interference by iodinated agents with the therapeutic iodine uptake.

Gadolinium based contrast agents are in general known to be safe and not nephrotoxic in the usual MRI doses of up to 0.3 mmol kg\(^{-1}\) body weight (BW) However, the dose requirement for a satisfactory diagnostic study differs between MR and X-ray examination because different properties of the gadolinium are being used in the two modalities. The use of gadolinium-based contrast agents in radiographic examinations is contentious and the risks are poorly understood (Thomsen et al. 2002; Thomsen 2003).

22.2 Molar Concentrations of Gadolinium and Iodinated Contrast Agents

The first four marketed gadolinium contrast media (gadopentate dimeglumine, gadoterate, gadodiamide, gadoteridol) are available in a concentration of 0.5 mmol ml\(^{-1}\). Gadobenate dimeglumine is also available in this concentration but unlike the other four agents, it is also excreted via the liver (4%) (Chap. 25). Gadobutrol has been introduced in a concentration of 1 mmol ml\(^{-1}\). For all the six agents there is one Gd-atom in each molecule, so the molar concentration of the agent and of gadolinium is the same. Traditionally, iodine radiographic contrast media are marketed based on the mg of iodine per ml. The concentration...
of 300 mg I ml\(^{-1}\) is equal to 2.38 mmol I ml\(^{-1}\). Since there are three iodine atoms per molecule, the molar concentration of the agent is only 0.8 mmol ml\(^{-1}\).

The commonly used dose for body CT is 150 ml of a 300 mg I ml\(^{-1}\) (2.38 mmol I ml\(^{-1}\)) solution. For body CT, a patient weighing 70 kg would receive 120 mmol of the iodinated agent molecule (0.8 mmol ml\(^{-1}\) × 150 ml) and 360 mmol of iodine (2.38 mmol ml\(^{-1}\) × 150 ml). The standard dose for contrast-enhanced MR examination is 0.2 ml kg\(^{-1}\) BW of a 0.5 mmol ml\(^{-1}\) gadolinium-based contrast agent. For MR examination, the same 70 kg patient would receive 7 mmol of the gadolinium based agent molecule and 7 mmol of gadolinium (0.5 mmol ml\(^{-1}\) × 14 ml (0.2 ml kg\(^{-1}\) BW × 70 kg BW)). Thus, the number of iodinated contrast agent molecules administered for CT would be almost 17 times that of gadolinium containing molecules for MR, and the number of iodine atoms administered would be 51 times that of gadolinium. For a patient weighing 50 kg, the difference is even larger [\(~24\) times (molecule) and \(~72\) times (atom)], whereas for a patient weighing 100 kg it is less [\(~12\) times (molecule) and \(~36\) times (atom)].

### 22.3 Attenuation of X-Rays by Iodine and Gadolinium

Iodine has the atomic number 53 and an atomic weight of 127, whereas gadolinium has the atomic number 64 and an atomic weight of 157. Attenuation increases with the atomic number of the atom but decreases with the energy (keV) of the X-ray photons, except at the K-edges. At photon energies between the K-edge of iodine [33 kilo electron Volt (keV)] and that of gadolinium (52 keV), iodine attenuates approximately twice as many X-ray photons as gadolinium does. At all other photon energies, the opposite prevails (Nyman et al. 2002). For CT, the maximal X-ray photon energy is between 120–140 keV and the most common photon energies in the spectrum are between 60–70 keV. This is above the K-edge of gadolinium, so the attenuation by gadolinium in this situation is about twice that of iodine; but since there are three iodine atoms per contrast medium molecule, the iodinated contrast agent molecule attenuates 1.5 times more radiation than the gadolinium-based contrast molecule does. For common radiographic examinations, the maximal X-ray photon energy is between 70–90 keV and the most common photon energies in the spectrum are above and below the K-edge of gadolinium (50 keV). Because of the range of photon energies, attenuation is approximately the same for iodine and gadolinium atoms. Hence, the attenuation by the iodinated contrast agent molecule is three times that of the gadolinium based contrast molecule (Nyman et al. 2002).

It should theoretically be possible to obtain radiographic images of diagnostic quality with gadolinium-based contrast agents, but the image quality will generally be inferior to that achieved with iodinated contrast agents. This can be explained by the difference in molar concentrations between gadolinium- and iodine-based contrast agents. A 0.5 mmol ml\(^{-1}\) concentration of iodinated contrast agent contains 63 mg I ml\(^{-1}\). Assuming that a 0.5 mmol ml\(^{-1}\) concentration of gadolinium based contrast agent attenuates to the same extent as a 0.5 mmol ml\(^{-1}\) concentration of the iodinated agent, a patient receiving these equi-attenuating concentrations receives only 1/3 of the contrast medium molecules with the iodinated agent that would be necessary with the gadolinium based agent. Considering the molar concentration of an iodinated contrast agent at 300 mg I ml\(^{-1}\), the attenuation of this preparation is almost five times that of gadolinium preparations of the same volume. Thus, the volume of gadolinium preparation required to obtain “comparable” attenuation is five times that of the iodine preparation.

### 22.4 Pharmacokinetics

The gadolinium chelates have pharmacokinetics similar to those of iodinated radiographic contrast agents with the exception of gadobenate dimeglumine which is also excreted by the liver in small amounts (Chap. 25). Gadobenate dimeglumine is however mainly used for non liver specific indications similar to the five other “extracellular” gadolinium chelates (Chap. 21). Both gadolinium and iodinated agents are distributed in the extracellular space and excreted by glomerular filtration. Thus, the T\(\frac{1}{2}\) is almost the same, and both types of agents can be used to measure the glomerular filtration rate. In patients with normal kidney function about 98% of these agents are excreted within 24 h of injection. However, in patients with severe renal impairment,