Gadolinium-Based Magnetic Resonance Imaging Contrast Agents in Interventional Radiology

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Abstract

Gadolinium-based agents are widely used in magnetic resonance imaging as contrast agents. These agents are radio-opaque enough for diagnostic imaging of the vascular tree by using digitally subtracted images as well as for imaging of the biliary system and the urinary tract. The recommended doses for gadolinium do not impair renal function or cause adverse reactions in patients with iodine sensitivity; thus patients with such conditions can safely undergo diagnostic angiography, either by MRI angiography or by catheterization using gadolinium as contrast agent, for diagnostic and therapeutic purposes.

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Iodine-based contrast agents are the gold standard agents for angiographic procedures. Even with the implementation of the new low osmolar and non-ionic contrast agents that reduce iodine damage to the kidney's function, severe side effects such as renal failure and even death still occur. In patients with pre-existing renal insufficiency, contrast nephrotoxicity is reported to occur in up to 30% [1]. In up to a quarter of these patients transient dialysis is required, and in a third of these patients renal impairment remains permanent [2].

These complications have led to three different solutions. One is the use of alternative imaging modalities, such as duplex color-flow ultrasound, intravascular ultrasound, and lately, magnetic resonance angiography. Using MRI, one can visualize the vascular tree without need of contrast medications, using sequences like phased contrast images and time of flight images [3] and, more accurately, by injecting gadolinium-based contrast enhancement agents in the new MR magnets [4]. The second solution is the use of medications that protect the kidneys from the toxic effects of the iodine. These drugs include: dopamine-3 agonist, phenoldopam, which causes renal vasodilatation [5], and acetylcysteine, which works in two ways: as a free radical scavenger and as a mild renal vasodilatant [6]. The third solution is to use alternative contrast agents like CO_2 [7] and, lately, gadolinium-based contrast agents both in interventional diagnostic and therapeutic procedures. Carbon dioxide is a gas that can be imaged intravascularly by using digital subtraction angiography. Its use, however, is limited to below the diaphragm because of a potential risk of intracerebral gas emboli or entrapment. CO_2 is also less visible in large vessels.

Gadolinium is a rare earth element with a K edge of 50.2 KeV (versus 33 Kev for iodine), a property that enables its imaging by using X-rays. Free gadolinium is toxic and excreted slowly over several weeks, thus it cannot be used unbound. To overcome its toxicity the gadolinium is chelated to other chemicals, which causes more rapid extraction, thus reducing its toxicity. There are many documented studies on the safety of using intravenously administered gadolinium contrast agents in MR imaging in doses up to 0.4 mmol/kg in patients with renal insufficiency [8]. The overall incidence of adverse events is less then 5% and they consist mainly of mild reactions such as headaches, nausea and emesis. The incidence of anaphylactoid reactions is 1:100,000–500,000 higher in patients with history of reaction to iodine [9,10]. Gadolinium-based contrast agents are eliminated almost exclusively by the kidney with a half-life of approximately one and a half hours. In patients with renal failure the excretion may even take several days. Gadolinium can be successfully removed with dialysis [11].

The safe intravenous use of gadolinium in MR imaging and its physical properties (high K edge) makes it a good potential contrast agent in angiography. Phantom experiments show that gadolinium exhibits image contrast equal to one-eighth to one-quarter of the strength of iodine preparations containing 300 mg/dl of iodine and equal to half of the strength in thicker tissues (like the abdomen). Because of the dose limitation and the rapid flow in the arteries, gadolinium is best visualized with full-strength administration using high quality digitally subtracted images techniques available in most angiographic machines. It is best visualized with selective injections, either by hand or using a power injector, in vessels less than 1 cm in diameter at a frame rate of two to three images per second [12]. Its physical properties also enable reduction of about 10% in the radiation dose compared to iodine contrast agents and even lower in thinner patients. This radiation dose reduction is achieved by increasing the gadolinium dose by 180%. The higher dose reduces the quantum mottle effect seen with lower KVp [12].

Several gadolinium preparations are approved by the U.S. Food and Drug Administration for intravascular use. Some of these preparations are low osmolar (600–800 mOsm/kg water) and the rest are high (about 2,000 mOsm/kg water). The lower osmolarity agents cause less pain during intraarterial injection in the extremities and may be less nephrotoxic when administered directly into the renal artery [12]. Gadolinium can be administered by hand injection or by power injector.

The limitations of intraarterial use of gadolinium includes: possible transient pain during its injection in peripheral vessels especially when using the high osmolar formulas, decreased visualization of vessels larger than 1 cm, the dosage limit, and the need for DSA images to visualize flow. Gadolinium is more expensive than CO_2 and iodine, thus its use is indicated only when there are contraindications for iodine or CO_2 use.

Vascular use of gadolinium agents

Since there are no territories contraindicated for gadolinium use, unlike CO_2, gadolinium can be used in all body parts, including the intracranial vessels [13]. Large vessels like the aorta can be imaged with gadolinium using a power injector in doses of 20–40 ml of gadolinium [14]. However, imaging of the entire aorta by gadolinium is suboptimal because of the dilution of the agent, especially in cases of aortic aneurysms. In such patients, contrast-enhanced MRA is the preferred imaging modality.

Gadolinium-based agents can be used alone or in conjunction with CO_2 angiography both for diagnostic and therapeutic procedures. Because of the dose limitations of gadolinium, it is used in cases of CO_2 intolerance, in unclear CO_2 images (problem

DSA = digitally subtracted images
MRA = magnetic resonance angiography

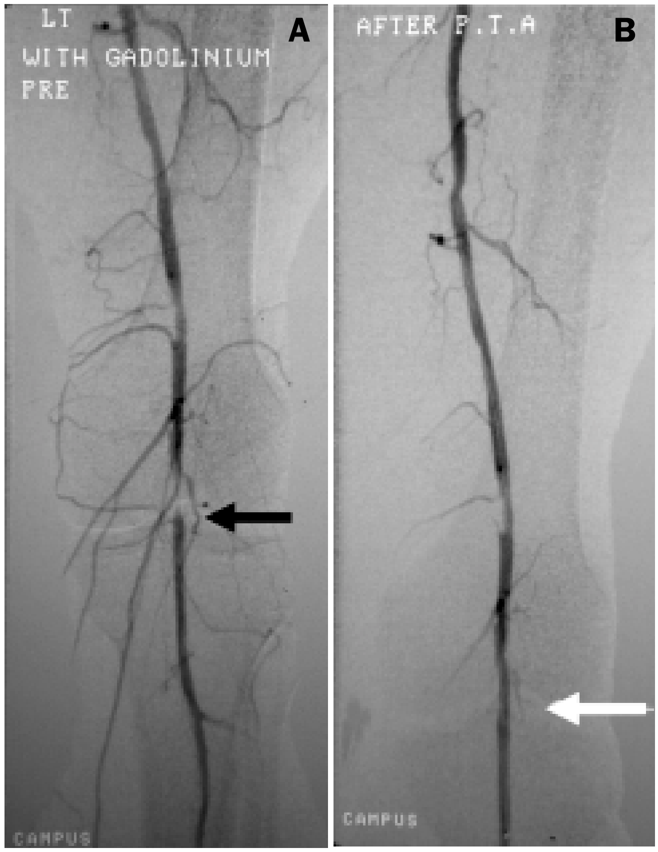
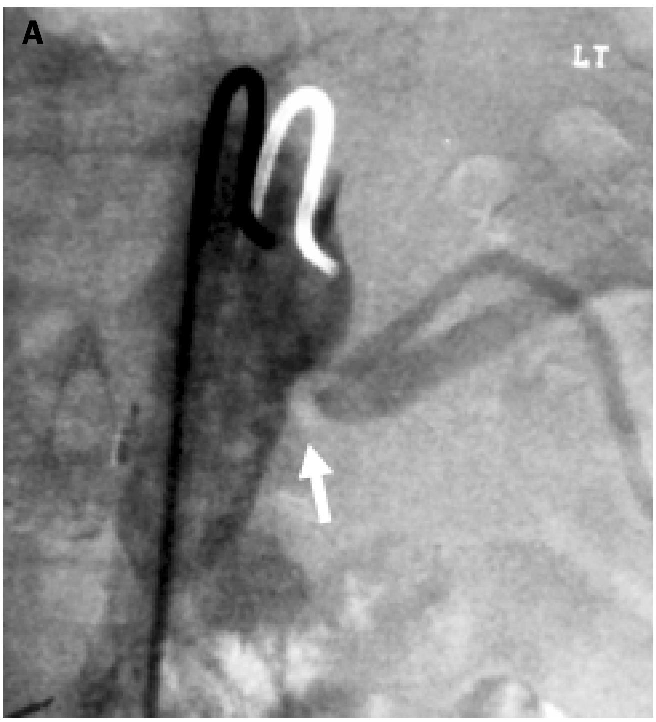


Figure 1. A young male with intermittent claudication in his left leg with impaired renal function underwent MRA which revealed a tight stenosis of his left popliteal artery. **[A]** Gadolinium-based angiography of the left lower extremity demonstrates the same lesion (arrow). **[B]** Gadolinium-based angiography obtained after balloon angioplasty of the stenosed segment demonstrates good results (arrow).



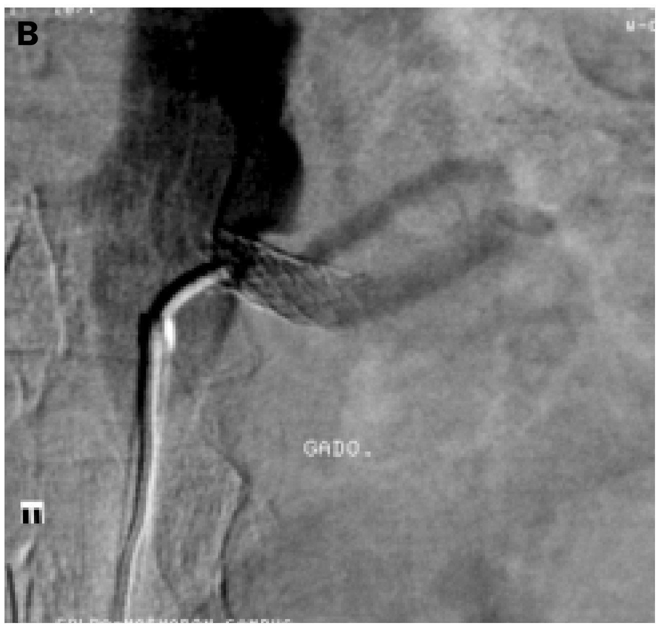


Figure 2. Bilateral renal artery stenosis and hypertension in a patient with impaired renal function diagnosed with CT angiography. **[A]** Angiography of the left renal arteries using gadolinium demonstrates tight stenosis of the dominant superior artery (arrow). **[B]** Gadolinium angiography after stent deployment in the dominant artery.

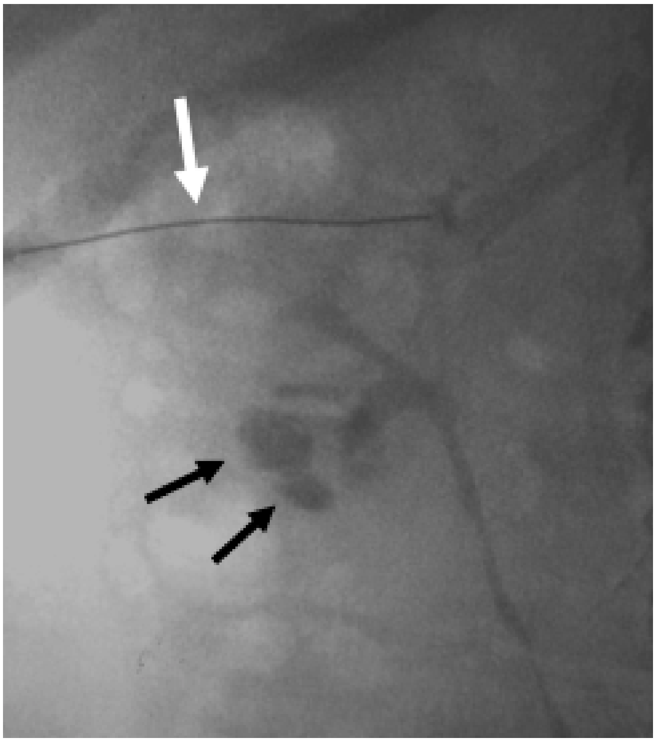


Figure 3. Antegrade pyelography through a small needle (white arrow) inserted in the upper renal calyx during nephrostomy placement prior to removal of two renal stones (black arrows) in a patient sensitive to iodine.

solver) or, as we use it, for medium and small vessel angioplasties based on MR angiographies [Figure 1A and B], or computed tomography [Figure 2A and B], or for diagnostic procedures when MRA is not available or contraindicated.

Non-vascular use of gadolinium agents

There are almost no medical reports on the role of gadolinium in non-vascular diagnostic and intervention procedures [15]. However, the biliary and genitourinary tracts can be imaged clearly by using gadolinium. Since these systems are slow flowing, gadolinium can be imaged also by fluoroscopy although the images have lower contrast compared with those obtained with iodine. Procedures such as nephrostomy tube insertion [Figure 3], percutaneous transhepatic cholangiography drainage or abscessography can be, and are, performed using gadolinium. I personally use gadolinium as a contrast agent in non-vascular emergent procedures in patients allergic to iodine when there is no time for proper preparation against allergic reactions.

Gadolinium contrast agents can be used as a safe and reliable alternative to iodinated contrast materials for vascular and non-vascular diagnostic and therapeutic interventional procedures in patients who are sensitive to iodine or who have impaired renal function. They can be used alone, together with CO_2 angiography, and even together with small volumes of iodine.

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Watch a man in times of adversity to discover what kind of man he is; for then at last words of truth are drawn from the depths of his heart, and the mask is torn off.

Lucretius (1st century BC), Roman philosopher and poet. His single work, The Nature of Things, consists of six books – the most complete exposition of the philosophy of Epicurus, including his atomic theory of phenomena and the belief that the soul is material (and mortal).