European Journal of Radiology 84 (2015) 1419–1423

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Review

# Measurement of single-kidney glomerular filtration function from magnetic resonance perfusion renography

Meiying Zeng[a], Yingsheng Cheng[a], Binghui Zhao[b,*]

[a] Department of Radiology, Shanghai Jiao Tong University Affiliated Sixth People's Hospital, Shanghai 200233, China
[b] Department of Radiology, Shanghai Tenth People's Hospital, Tongji University, Shanghai 200072, China

ARTICLE INFO

*Article history:*
Received 6 March 2015
Received in revised form 27 April 2015
Accepted 2 May 2015

*Keywords:*
Renal function
GFR
MR imaging
Functional imaging

ABSTRACT

Glomerular filtration rate (GFR) describes the flow rate of filtered fluid through the kidney, and is considered to be the reference standard in the evaluation of renal function. There are many ways to test the GFR clinically, such as serum creatinine concentration, blood urea nitrogen and SPECT renography, however, they're all not a good standard to evaluate the early damage of renal function. In recent years, the improvement of MRI hardware and software makes it possible to reveal physiological characteristics such as renal blood flow or GFR by dynamic contrast enhancement magnetic resonance perfusion renography (DEC MRPR). MRPR is a method used to monitor the transit of contrast material, typically a gadolinium chelate, through the renal cortex, the medulla, and the collecting system. This review outlines the basics of DCE MRPR included acquisition of dynamic MR perfusion imaging, calculation of the contrast concentration from signal intensity and compartment models, and some challenges of MRPR method faced in prospective clinical application.



Renal function is an indication of the state of the kidney in renal physiology and in nephrology. There are many ways to test renal function clinically such as serum creatinine concentration and blood urea nitrogen, endogenous creatinine clearance rate (Ccr), glomerular filtration rate (GFR), effective renal plasma flow (ERPF), etc. However, serum creatinine concentration and blood urea nitrogen are considered as markers of late renal dysfunction, which cannot find substantial and sometimes irreversible renal damage earlier, and also can't be used to assess single-kidney function. GFR or SPECT renography, which can describe the flow rate of filtered fluid through the kidney, is often applied as the reference standard in the evaluation of kidney function in clinic. Ccr are also important to reflect the renal flow and excretion, but they are not often applied due to complex examination process. And SPECT renography is the main imaging technology to evaluate renal functional information included GRF and ERPF at present, however, it is evidently lack of spatial resolution and cannot detect the early damage of renal function but also the latent exposure to ionizing radiation [1].

MR imaging is playing an important role in evaluating kidney's diseases and morphological changes due to its high resolution. And recent years, the improvement of DCE MR perfusion imaging (DCE MRPR) techniques whether hardware or software, make it possible to reveal renal physiological characteristics qualitatively and quantitatively such as GFR, even the ERPF and renal excreting function, and it's being applied to detect the blood flow or transfer constant and concentration of interesting organ or tissue through tracing contrast agent-Gd-DTPA as the pharmacokinetic modeling. And low dose of contrast agent and no radioactive damage were also recommended [2,3]. In this article, we outline the techniques of DCE MRPR to evaluate renal function quantitatively, and some new challenges of MRPR faced in prospective clinical application.

## 1. Renal physiology and imaging tracer agent

In normal states, the kidneys receive about 25% of total cardiac output, or about 600–700 mL/min of plasma in other words. This reflects the importance of the kidney in maintaining homeostatic balance of bodily fluids by filtering, secreting and resorbing metabolites and minerals, and then excreting waste materials along with water as urine.

Glomerular filtration rate (GFR) and effective renal plasma flow (ERPF) are two important factors to reflect the renal function. GFR has classically been calculated by measuring the clearance of a substance from the plasma which is neither secreted nor reabsorbed by the renal tubules, such as polysaccharide insulin or isothalamate,

* Corresponding author. Tel.: +86 13916342617.
*E-mail address:* binghuizhao@163.com (B. Zhao).

http://dx.doi.org/10.1016/j.ejrad.2015.05.009
0720-048X/

and it may evaluate the renal function by calculating the amount of plasma filtered through Bowman's capsule into the urine per unit time. In clinic, SPECT is the mainly imaging technique to reflect the kidney GRF and ERPF, $^{99m}$Tc-DTPA or $^{99m}$Tc-EC is usually applied because its characteristics are the same as insulin or isothalamate but ionizing radiation.

Low-molecular weight (<1000 Da) gadolinium contrast agents such as Gd-DTPA or Gd-DOPA, commonly used in clinical MRI, are extravascular and extracellular tracers, almost 98% percent being eliminated by glomerular filtration without any tubular secretion or reabsorption just like insulin. Therefore, these agents can be used to calculate GFR and ERPF with DCE MR perfusion imaging and images proceeded and visualized by special software [4].

## 2. Foundational concepts

DCE MR perfusion imaging is a technique that performed with the intravenous injection of a contrast agent (commonly based on gadolinium chelates) and continuously imaging to monitor the traversal of the tracer within the tissue and generating signal intensity–concentration curves. Parameters related to tissue can be calculated by analyzing concentration curves with either model-based or model-free approaches [5]. DCE MR perfusion imaging of the kidneys, that is MR perfusion renography (MRPR), is used to continuously monitor the transit of contrast material, typically a gadolinium chelate, through the renal cortex, the medulla, and the collecting system. Through analysis of concentration–time curves, converting from intensity-time curves, with model-based approaches, clinically important single kidney parameters such as renal blood flow, GFR, and cortical and medullary blood volumes can be determined [2].

## 3. Technique

Most methods of calculating GFR based on MRPR need three steps below: acquisition of dynamic magnetic resonance perfusion images; generation of MRPR by converting the signal intensity of the renal tissue to gadolinium concentration; obtaining of GFR and other functional parameters based on two or more compartment models.

## 4. Dynamic MR acquisition

### 4.1. Sequence choice

The ideal pulse sequence would have a heavy T1-weighting, excellent signal-to-noise ratio (SNR), be very fast, and the signal changes induced by Gadolinium-Based Contrast Agent (GBCA) should have a linear relationship with the concentration of the GBCA [6]. The pulse sequences can be divided into two broad categories according to whether they use a spin-echo or a gradient recalled echo (GRE) to form the signal. For the faster speed and higher SNR, 2D or 3D GRE sequences are generally selected for DCE imaging. The essential difference between 2D and 3D methods is that 2D acquisitions always contain a non-selective inversion- or saturation prepulse. In combination with a low flip angle, this serves to minimize inflow effects in the larger vessels. In a 3D sequence, inflow effects are minimized by positioning the slab so that the major artery travels a large enough distance through the slab. Fast 3D acquisition has become feasible and is gradually replacing 2D approaches in current practice. On one hand, GBCA shorten the T1 and T2 relaxation times, and its effect on T1 relaxation time is greater. On the other hand, there is a linear relationship between the relaxation rate and the concentration of GBCA. As a result, T1-weighted sequence is mostly applied in dynamic renal studies [7]. A reasonable T1 weighting can be accomplished using spoiled GRE (SPGR) with a short echo-time (TR), a relatively high flip angles (45–90°), and a short echo-time (TE) [8,9]. In DCE-MRI, TE is chosen near its minimal value in order to minimize $T_2^*$ effects, which will result in signal decay due to the inhomogeniety dephase. For the temporal resolution, TR is usually minimized too.

### 4.2. Dose of contrast

High doses of gadolinium chelate should be avoided for two reasons. One is the $T_2^*$ susceptibility effect, as said above, and the other is the high perfusion of kidneys. During the intravenous bolus injection of contrast agent, when the concentration in kidneys and the abdominal aorta beyond the dynamic range of the sequence, the signal one will reach a saturation regime and no longer be sensitive to changes. There is no consensus about the optimal dose to be used in the literature. Rusinek et al. [9] show that the highest GFR precision is achieved at an approximately 0.02 mmol/kg (~4 mL) dose of gadolinium in healthy persons and approximately 0.025 mmol/kg (~5 mL) in patients with decreased renal function. But the fewer doses will reduce the contrast to noise ratio (CNR). Considering the latent renal function damage led by contrast agent and the patient's renal disease and possible decreased renal function, also was the low dose of contrast agent adopted in our study (Gd-DTPA, 0.025 mmol/kg) and it showed that it's enough to evaluate the renal function and latent renal disease for most patients (Figs. 1 and 2).

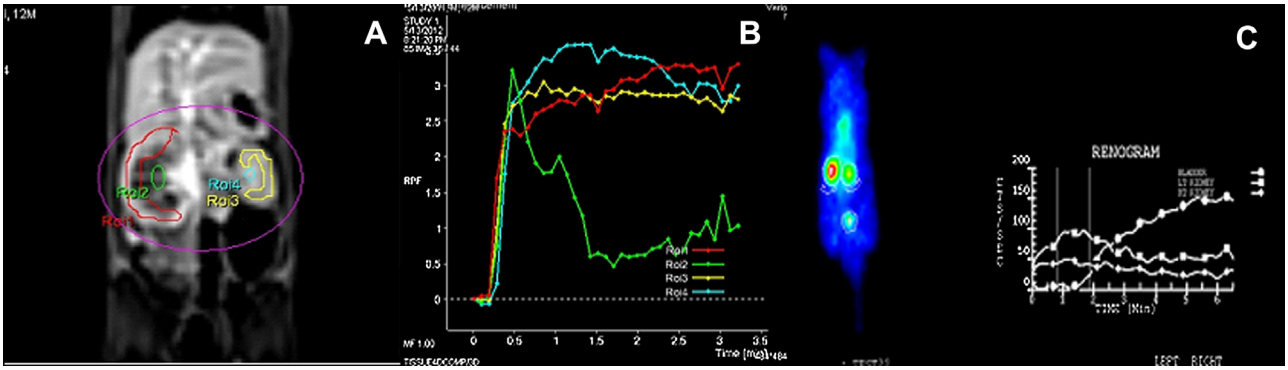


**Fig. 1.** Images of rat with left renal artery stenosis by DCE MRPR. Left kidney was atrophy, and bilateral renal parenchyma and pelvis area was outlined (A) and calculated the time-MIP curve at workstation (B), compared with SPECT renography (C). The contrast-enhancement degree of left kidney parenchyma was slightly lower than right kidney, however, the Gd-DTPA excreted rate of left kidney was greatly lower than that of right kidney. (A and B) ROI 1 and ROI 2 are outlined parenchyma and pelvis of right kidney; ROI 3 and ROI 4 are outlined parenchyma and pelvis of left kidney. (C) (■) Right kidney; (♦) left kidney; (●) bladder.