Available online at www.sciencedirect.com

ScienceDirect

European Journal of Radiology Open 2 (2015) 71–80

EUROPEAN JOURNAL OF RADIOLOGY OPEN

www.elsevier.com/locate/ejro

Diffusion weighted imaging and diffusion tensor imaging in the evaluation of transplanted kidneys

Stefano Palmucci [a,*], Giuseppina Cappello [a], Giancarlo Attinà [a], Pietro Valerio Foti [a], Rita Olivia Anna Siverino [a], Federica Roccasalva [a], Marina Piccoli [a], Nunziata Sinagra [b], Pietro Milone [a], Massimiliano Veroux [b], Giovanni Carlo Ettorre [a]

[a] *Radiodiagnostic and Radiotherapy Unit, University Hospital "Policlinico-Vittorio Emanuele", Via Santa Sofia 78, 95123 Catania, Italy*

[b] *Vascular Surgery and Organ Transplant Unit, Department of Surgery, Transplantation and Advanced Technologies, University Hospital "Policlinico-Vittorio Emanuele", Via Santa Sofia 78, 95123 Catania, Italy*

Received 12 March 2015; accepted 4 May 2015
Available online 16 May 2015

Abstract

Objective: The aim of this study is to investigate the relation between renal indexes and functional MRI in a population of kidney transplant recipients who underwent MR with diffusion-weighted imaging (DWI) and diffusion tensor imaging (DTI) of the transplanted graft.

Method: Study population included 40 patients with single kidney transplant. The patients were divided into 3 groups, on the basis of creatinine clearance (CrCl) values calculated using Cockcroft-Gault formula: group A, including patients with normal renal function (CrCl $\geq$ 60 mL/min); group B, which refers to patients with moderate renal impairment (CrCl > 30 but <60 mL/min); and, finally, group C, which means severe renal deterioration (CrCl $\leq$ 30 mL/min). All patients were investigated with a 1.5 Tesla MRI scanner, acquiring DWI and DTI sequences. A Mann–Whitney *U* test was adopted to compare apparent diffusion coefficients (ADCs) and fractional anisotropy (FA) measurements between groups. Receiver operating characteristic (ROC) curves were created for prediction of normal renal function (group A) and renal failure (group C). Pearson correlation was performed between renal clearance and functional imaging parameter (ADC and FA), obtained for cortical and medullar regions.

Results: Mann–Whitney *U* test revealed a highly significant difference ($p < 0.01$) between patients with low CrCl (group C) and normal CrCl (group A) considering both medullar ADC and FA and cortical ADC. Regarding contiguous groups, the difference between group B and C was highly significant ($p < 0.01$) for medullar ADC and significant ($p < 0.05$) for cortical ADC and medullar FA. No difference between these groups was found considering cortical FA. Analyzing groups A and B, we found a significant difference ($p < 0.05$) for medullar both ADC and FA, while no difference was found for cortical ADC and FA.

Strongest Pearson correlation was found between CrCl and medullar ADC ($r = 0.65$). For predicting normal renal function or severe renal impairment, highest values of AUC were observed using medullar ADC cut-off values (respectively 0.885 and 0.871); medullar FA showed also high accuracy (respectively 0.831 and 0.853).

Conclusions: DWI and DTI are promising tools for non-invasive monitoring of renal function; medullar ADC proved to be the best parameter for renal function assessment.

Keywords: Magnetic resonance imaging; Diffusion weighted MRI; Diffusion tensor imaging; Kidney transplantation

1. Introduction

Renal graft function is monitored using clinical parameters – such as serum creatinine, creatinine clearance – and imaging modalities, mainly represented by ultrasound, ecocolor-doppler and scintigraphy; however, the assessment of renal disease requires parenchymal biopsy to make a correct diagnosis, grading also the level of damage. Renal biopsy is an invasive

Abbreviations: DWI, diffusion weighted imaging; ADC, apparent diffusion coefficient; DTI, diffusion tensor imaging; FA, fractional anisotropy; CrCl, creatinine clearance; ROI, region of interest; ROC, receiver operating characteristic curve; AUC, area under the curve.

* Corresponding author. Tel.: +390953782360; fax: +390953782368.
E-mail address: spalmucci@sirm.org (S. Palmucci).

http://dx.doi.org/10.1016/j.ejro.2015.05.001

procedure, not free from complications (hemorrhage, infection, etc.). In a recent study by Franke et al., a not-irrelevant number of complications (perirenal/retroperitoneal bleeding, hematuria, arterio-venous fistula) have been found; indeed, the complication rate was 4.1% [1].

The possibility of investigating renal function is one of the most recent goals of functional MRI; namely, this potentiality has been gradually increased in importance due to the fact that gadolinium enhanced MRI has a non-negligible degree of nephrotoxicity [2,3].

In the past decade, several articles have pointed out the role of functional MRI in the evaluation of kidney diseases [4]. DWI has been used to characterize focal renal lesions [5], and to investigate renal function, either in normal kidneys [6] or renal graft also [7].

All renal functions, such as glomerular filtration, tubular reabsorption and secretion, are based on water transportation [8]. Thus, quantification of Brownian motions measured by DWI may provide a functional assessment of renal parenchyma. Diffusion and perfusion effects are expressed by a numerical value, named ADC, which decreases with restriction of diffusion of water molecules. ADC is defined as "an average index of how freely water can move within a voxel (i.e. averaged across all tissue structures and compartments within the voxel) and hence the term apparent" [9].

However, molecular motility may not be the same in all directions, leading to a certain anisotropy. It can be due for example to an obstacle limiting molecular movements or to the anatomic orientation of the structures of the tissue. DTI is able to evaluate diffusion anisotropy measuring diffusion of water molecules for each single direction of the gradient pulses. DTI allows us to obtain in vivo information about oriented tissues, such as brain white matter, muscles and myocardium [10]. Its role has been emphasized in brain study, particularly in patients with brain tumors to evaluate displacement or interruption of white matter pathways, and in demyelinating disease to detect subtle changes in myelin fibers integrity [11]. As in brain white matter, also in renal medulla there is an intrinsic orientation of the structures because it is assembled in tubuli and ducti with parallel coarse. Thus, several studies have pointed out that normal renal architecture suggest a different evaluation of diffusion direction using DTI, that could be able to evaluate the degree of medullary anisotropy [12].

The purpose of our study was to evaluate the usefulness of DWI and DTI in assessing allograft dysfunction correlating ADC and FA values with laboratory data; diagnostic accuracy of ADC and FA is calculated, in order to investigate which is the most useful parameter for the evaluation of renal function.

2. Material and methods

2.1. Study population

Patients were enrolled between September 2014 and January 2015. This study was approved by our internal ethics committee and a written informed consent was obtained from all patients before MRI.

Study population included forty patients with single kidney transplant (24 males, 16 females) with a mean age of 50.6 years (range, 17–78). 32 of them received transplant from deceased donor, 8 from living donor. A serum creatinine value was collected no more than 36 h before or after MRI examination.

Patients received a standard immunosuppressive protocol with a calcineurin inhibitor (tacrolimus in 27 and cyclosporine in 13), mycophenolatemofetil and steroids. None of the patients experienced an episode of acute rejection during the study period. MRI examinations were performed at a mean post-transplant time of 3.8 years (range, 8 days-22.8 years). No patients were excluded from this study.

Kidney transplantations, clinical management and follow-up were performed by the same surgical team. All transplanted kidneys were placed in the right iliac fossa with vascular anastomoses to the common or external iliac vessels. The patients were divided into 3 groups, on the basis of CrCl values calculated using Cockcroft-Gault formula:

- group A, patients with CrCl $\geq$ 60 mL/min;
- group B, patients with CrCl > 30 but <60 mL/min;
- group C, patients with CrCl $\leq$ 30 mL/min.

2.2. MRI protocol

All examinations were performed using a 1.5 Tesla scanner (SignaHDxt, General Electric). Images were acquired with an 8-channels array coil (8 channel body coil), using the lower configuration; sequences were not respiratory-triggered, so that no "respiratory" belt was used.

Unenhanced T1 and T2-weighted sequences were performed before DTI in order to obtain a morphological evaluation of transplanted kidneys. Axial sequences were positioned perpendicularly to the major axis of the kidney (Fig. 1). No intravenous hypotonic agent was administrated. Protocol examination included:

- Axial T2-weighted Fast Recovery Fast Spin Echo sequence, obtained with a TR = 3200 ms, TE = 110 ms, thickness = 5 mm, gap interval = 0.5 mm, Number of Excitations = 4, matrix = 320 × 224, Field of View = 36–40;
- Coronal T2-weighted Fast Recovery Fast Spin Echo sequence, obtained with a TR = 3100 ms, TE = 103 ms, thickness = 3 mm, gap interval = 0.3 mm, Number of Excitations = 4, matrix = 320 × 224;
- Diffusion-weighted sequences, obtained by Single Shot Echo Planar Imaging technique, using a b value of 500. Namely, acquisition parameters were the following: TR = 3000 ms; TE = 40–79 ms; Number of Excitations = 2; acceleration factor = 2; EPI factor = 80; thickness = 5 mm; spacing = 1 mm; Field of View = 34–42; matrix = 128 × 128, acquisition time = 1 min 42 s.
- DTI was acquired using a "free-breathing" Single Shot Echo Planar Imaging technique, with diffusion gradient active for 6 directions. Acquisition parameters were: TR = 7500 ms;