The Egyptian Journal of Radiology and Nuclear Medicine xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

The Egyptian Journal of Radiology and Nuclear Medicine

journal homepage: www.sciencedirect.com/locate/ejrnm

Original Article

The role of kidney diffusion tensor magnetic resonance imaging in children

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ARTICLE INFO

Article history:
Received 4 April 2016
Accepted 19 August 2016
Available online xxxx

Keywords:
Renal DTI
Pediatric
eGFR
Renal insufficiency
Radiology

ABSTRACT

Background: Diffusion tensor imaging (DTI) in magnetic resonance imaging (MRI) provides information about the microstructure of renal tissue and is becoming increasingly useful in the evaluation of relationship between renal structure and function.
Objectives: To investigate, whether DTI allows assessment of renal impairment and pathology in pediatric patients with decreased renal functions.
Materials and methods: Thirty-two pediatric patients and seventeen healthy children were included in this prospective study. For DTI, a respiratory-triggered coronal echo planar imaging (EPI) sequence was performed. Cortical and medullary mean axial and radial diffusivity and fractional anisotropy (FA) were analyzed.
Results: In healthy subjects, the cortical FA values were significantly lower than the medullary FA values ($p < 0.001$). Cortical and medullary ADC values showed positive correlations ($r = 0.499$, $p = 0.041$) and a negative correlation with cortical FA values($r = -0.533$, $p = 0.028$). The eGFR values were negatively correlated with the medullary ADC values ($r = -0.484$, $p = 0.049$) in healthy subjects and positively correlated with the λ medullary values ($r = 0.385$, $p = 0.027$). Additionally in the patient group, the age was positively correlated with FA cortex values ($r = 0.411$, $p = 0.018$) and with the medullary ADC values ($r = 0.461$, $p = 0.007$). However, the medullary FA values were negatively correlated with the medullary ADC values ($r = -0.363$, $p = 0.038$). Tractography of healthy volunteers showed a radial arrangement which converged into the pyramids, whereas renal insufficiency patients had irregular arrangement patterns and architectural distortions in the observed areas.
Conclusions: Renal DTI is a promising diagnostic tool in the assessment of microstructural renal changes and correlates with the eGFR. Therefore, it is possible to estimate the arrangement of the tracks which emanate from the renal medulla. Furthermore, diffusion of the water molecules could be carried out. This study demonstrates the usage of DTI in renal pediatric kidneys. Validations in larger cohort groups with histopathological biopsies are needed.

Peer review under responsibility of The Egyptian Society of Radiology and Nuclear Medicine.
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http://dx.doi.org/10.1016/j.ejrnm.2016.08.015
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Please cite this article in press as: Özkan MB et al. The role of kidney diffusion tensor magnetic resonance imaging in children. Egypt J Radiol Nucl Med (2016), http://dx.doi.org/10.1016/j.ejrnm.2016.08.015

1. Introduction

The major function of the kidneys is to balance the water and solute concentration. Kidneys do this physiologically by the help of glomeruli and tubules, which enable filtration and reabsorption of water and solutes [1–4]. Understanding the basic mechanisms of water diffusion in the kidneys could help to improve the understanding of kidney pathologies. Laboratory parameters, such as serum creatinine or estimated glomerular filtration rate (eGFR), are commonly used for the evaluation of renal tubular function [5–7].

Diffusion weighted imaging (DWI) visualizes water motion at the molecular level and provides useful information on parenchyma microstructure and function, basically depending on the Brownian motion [5–7]. The apparent diffusion coefficient (ADC) is a quantitative parameter calculated from DWI [1]. It was shown that ADC values tend to decrease in chronic kidney diseases, depending upon the degree of renal impairment [5,8].

Kidneys have a well-defined anatomical structure with tubules, collecting ducts and vessels radially oriented toward the pelvis and in which molecules move in a preferential direction [9,10]. To investigate molecular diffusion in kidneys, the direction should be evaluated. In healthy kidney vessels, tubules and collecting ducts are involved in water reabsorption and urine formation. These structures have a highly perfectly organized radial arrangement. This kind of arrangement enables motion of water molecules to move in different directions, such as right to left or superior to inferior. Therefore, this is the reason for the anisotropic manner of the molecular diffusion in renal parenchyma [9]. This highly perfectly designed structural organization gets damaged in pathological processes. This relationship was demonstrated by previous studies [5,6,9,11].

DTI enables to measure the diffusion of the water molecules in at least six vectoral ways. The diffusion anisotropy could be used to understand the microstructure of the renal parenchyma. The fractional anisotropy (FA) describes the degree of anisotropy of a diffusion process whereas ADC describes only the averaged diffusivity in the directional way. Therefore, DTI enables to estimate and to measure the vectoral way of least restricted diffusion [3,12,13].

In the literature, the correlation between age-dependent changes and the ability of DTI to estimate renal tissue injuries due to tumors, pyelonephritis and renal artery stenosis was demonstrated. Additionally, it is known that the renal medulla has higher FA values than the cortex [5,9,14].

Studies in adults have demonstrated the ability to show microstructural changes correlating with functional parameters by utilizing DTI [3,4,9,15–16]. This prospective study's purpose was to examine the value of renal DTI in children and adolescents.

2. Material and methods

Divided into two cohorts (normal eGFR of ⩾60 ml/min/1.73 m^2, and reduced eGFR between ⩾25 ml/min/1.73 m^2 and <60 ml/min/1.73 m^2), a total of 50 children were included in this prospective single center study. A healthy control group consisted of 17 volunteers, the study group of 33 children. The control group consisted of nine males and eight females with a mean age of 8 ± 0.9 years (3.09–14.7 years). The mean age in the study group was 8.5 years ± 0.7 years (3.02–15.3 years), consisting of 20 male and 12 female children. One patient had to be excluded from this study group, as corticomedullary differentiation (CMD) had not been reported.

All of them underwent renal DTI, as further described in the renal MRI acquisition section. The duration of the study was one and half year. To be certain about the absence of renal parenchymal disease, volunteer patients additionally underwent a renal ultrasound examination.

Exclusion criteria were MRI contraindications such as ferromagnetic implants or claustrophobia. Because of a possible risk of nephrogenic systemic fibrosis [17], patients with GFRs lower than 25 were not included in the study.

The dimensions and corticomedullar differentiation were controlled before the renal MRI examination. All the values regarding these parameters were within normal values. Regarding the b:0 image values differentiation between the cortex and the medulla could be easily evaluated and able to be understood the object regions and edges.

A study group sub-group, representing patients with renal impairment (eGFR ⩾ 25 and equal or lower 40), was defined. eGFRs were calculated from serum creatinine measurements for all subjects based on the revised Schwarz formula for children and adolescent [18]. The patients were sedated under the age of eight. They were sedated by local anesthesiological products.

The study was approved by the institutional review board and written consent was obtained from the parents of all children.

3. Renal MRI acquisition

All subjects were scanned in supine position in an Avanto 1.5 T (T) MRI scanner (Siemens Medical Systems, Erlangen, Germany). Spine array (posterior) and body array (anterior) receiver coils were used to maximize image uniformity. The imaging protocol consisted of a respiratory-gated (axial 2D, 3D) echo-planar fast spin echo sequence (HASTE) and a coronal T2-weighted sequence. *After the HASTE sequence, a respiratory-gated, single-shot diffusion tensor imaging – echo planar imaging (DTI-EPI) acquisition was performed on one kidney (b = 0 and 400 s/mm^2, 6 directions + null, TR/TE = 2000 ms/75 ms, imaging slice thickness = 3 mm, 10 imaging slices/subject*). In order to achieve a better resolution and higher SNR values, either the left or right kidney was evaluated. Only single renal evaluation was enough for the determination.

In all children diffusion MR images were acquired prior to the administration of gadolinium. As a routine part of this renal MRI imaging, we had to use the gadolinium administration in order to get the sufficient renal diagnosis except those under eGFR under 25. Although we had to use gadolinium as a part of imaging technique, the renal DTI was evaluated separately in another work station and the

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