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Changes of renal blood flow after ESWL: Assessment by ASL MR imaging, contrast enhanced MR imaging, and renal resistive index

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ABSTRACT

The annual incidence of stone formation is increased in the industrialised world. Extracorporeal shockwave lithotripsy is a non-invasive effective treatment of upper urinary tract stones. This study is aimed to evaluate changes of renal blood flow in patients undergoing extracorporeal shock wave lithotripsy (ESWL) by arterial spin labeling (ASL) MR imaging, contrast enhanced dynamic MR imaging, and renal resistive index (RI). Thirteen patients with nephrolithiasis were examined using MR imaging and Doppler ultrasound 12 h before and 12 h after ESWL. ASL sequence was done for both kidneys and followed by contrast enhanced MR imaging. In addition RI Doppler ultrasound measurements were performed. A significant increase in RI ($p < 0.001$) was found in both treated and untreated kidneys. ASL MR imaging also showed significant changes in both kidneys ($p < 0.001$). Contrast enhanced dynamic MR imaging did not show significant changes in the kidneys. ESWL causes changes in RI and ASL MR imaging, which seem to reflect changes in renal blood flow.

1. Introduction

Extracorporeal shockwave lithotripsy (ESWL), first described in early 1980s, is a non-invasive, efficacious, and first-line treatment for upper urinary tract stones. The concept of being safe is under debate, based on evidence that ESWL can cause adverse effects, as the energy produced by ESWL has the capacity to damage renal tissue [1].

This treatment was found to have different acute and chronic complications. Several authors described transient and persistent changes in renal morphology and function. Examinations with scintigraphy, MR imaging, computed tomography (CT), ultrasound (US), different blood and urine laboratory parameters and histopathologic animal studies described damages of the glomerular, tubular and vascular system of the treated and kidneys [2,3]. A transient decrease in renal perfusion, causing ischemic injury was found in the contralateral (untreated) kidney too [4].

The resistive index (RI) is a non-invasive method and allows for assessment of changes in renal vascular resistance as a result of vascular compliance [5]. However, the correlation between the RI and renal perfusion decreases in cases of reduced compliance of renal vessels due to several diseases (i.e. atherosclerosis) [6].

Knapp et al. [2] described an increase in RI immediately after ESWL, and the most significant increase was found in elderly (older than 60 years).

MR imaging has shown to be useful for non-invasive measurement of perfusion [7]. Spin labeling technique can measure renal perfusion without usage of contrast media [8]. Currently this technique has been commonly employed for the assessment of muscle

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blood flow and cerebral perfusion [9]. The basic idea of arterial spin labeling (ASL) with the "signal targeting with alternating radiofrequency" (STAR) method is to suppress the signal intensity of the stationary tissue and to image the inflowing blood, which was labeled proximally with respect to blood flow. The difference in the measurements between the labeled and the unlabeled images represents the regional blood flow [10].

Furthermore dynamic contrast enhanced (DCE) MR imaging is used to assess microcirculatory tissue parameters. For that purpose, saturation recovery fast gradient echo sequences (i.e. TurboFLASH) are mainly used [11]. However, these methods necessitate sophisticated analysis procedures, which are not widely available, limiting the practical use [12].

We assessed changes in renal perfusion in patients undergoing ESWL using RI, ASL MR imaging and DCE MR imaging.

2. Patients and methods

Thirteen patients (mean age 49 ± 13 years) with renal stone disease were included in this study. Written informed consent was obtained from each patient. Prior ESWL baseline US, intravenous urography or CT urography, urine and blood analyses were done.

A Philips electrohydraulic lithotripter (Lithodiagnost M, USA) was used. The mean number of shock waves in each patient was 2838 ± 355. Treatment was done with kilovoltages (kV), varying between 18 and 24 kV. The lithotripter was positioned with the aid of fluoroscopy and/or ultrasound in all patients to guarantee accurate focus targeting. These ESWL procedures were adopted in all patients in the same way.

Exclusion criteria for this study were treated and untreated arterial hypertension, diabetes mellitus, vessel diseases, nephropathy, urinary tract infection, acute or chronic hydronephrosis and acute flank pain.

2.1. MR imaging examination protocol

MR imaging was performed on a 1.5 T Magnetom VISION plus whole body scanner (Siemens, Erlangen, Germany) using a body phased array coil. Each patient was examined 12 h before and 12 h after ESWL.

2.1.1. Arterial spin labeling

For perfusion imaging without a contrast agent we applied a pulsed ASL technique based on "signal targeting with alternating radiofrequency" (STAR) as originally described by Edelman et al. [8]. We implemented the STAR technique using a snapshot "fast low angle shot" (FLASH) readout (TR = 4 ms; TE = 2.1 ms; $\alpha = 4^\circ$; slice thickness = 6 mm; FOV = 220 mm; acquisition matrix: 64×128) to reduce artifacts. In the following, this sequence will be called FLASH–STAR sequence. As in the original approach a slice selective inversion pulse (TI = 1000 ms, thickness: 70 mm) was applied to a region outside (40 mm shift in proximal direction) of the imaging section ("inflow inversion") after a pre-saturation pulse (thickness: 15 mm), which is applied to the plane of the acquired image. Images are obtained in an alternating fashion without and with inflow inversion pulse, however, with otherwise identical gradient and sequence timing as well as pre-saturation pulses. Subtraction images between the alternating acquisitions without and with inflow inversion were obtained containing information about local blood flow. The total scan time for one snapshot FLASH-STAR acquisition was approximately 15 s. The measurements were repeated for 9 different slice positions covering the treated and untreated kidneys.

2.1.2. Dynamic contrast enhanced MR imaging

DCE perfusion imaging was performed using a saturation recovery snapshot FLASH sequence (16 slices, TR = 71 ms, TE = 2.1 ms, TI = 1000 ms, flip angle = 8°, slice thickness: 6 mm, slice gap: 1.8 mm, acquisition matrix: 64×128). For dynamic imaging the sequence was repeated 30 times in a breath-hold state. To allow the patient sufficient recovery after each breath-hold the time-interval of successive acquisitions was chosen to be 20 s. The contrast agent was injected intravenously using a MR compatible injector (Medrad, Indianola, PA, USA) at a rate of 0.1 ml/s using a dose of 7 ml of a Gd-DTPA (Magnevist, Bayer-Schering, Berlin, Germany). Injection was started after two initial pre-contrast acquisitions.

2.1.3. Corrections of changes in T1 relaxation

To calculate changes of relaxation rate pre-contrast tissue T1-values were acquired using a fast T1-mapping sequence based on an inversion recovery snapshot FLASH (IRSFL) sequence as originally described by Haase et al. [13]. Details of sequence implementation and T1-calculation have been already published [14]. In short, a total of 16 differently T1-weighted snapshot FLASH (TR = 3.9 ms, TE = 1.8 ms, flip angle $\alpha = 4^\circ$) images are acquired after an initial inversion pulse images, allowing the pixel-wise estimation of tissue T1 values using a low flip angle approximation as described earlier [14] with an error of less than 3%. The total acquisition time for one T1-map was 4 s. To cover both kidneys of the investigated patients T1-maps were obtained sequentially at the same slice positions as were later used for the dynamic saturation recovery sequence.

The obtained native T1 values were used to calculate concentration time curves from the saturation recovery data by manually drawing regions of interest (ROI). Motion of the kidneys during different breath-hold commands was corrected by a semiautomatic rigid body motion correction.

To get a measure of tissue blood flow from the obtained concentration time curves the maximum slope of the initial CA uptake was determined.

2.2. Image analysis

FLASH–STAR data were analysed by subtracting the images obtained with and without inflow inversion. The analysis was performed with a regular personal computer using the freeware software ImageJ (Rasband, W.S., ImageJ, U.S. National Institutes of Health, Bethesda, MD, USA, http://rsb.info.nih.gov/ij/, 1997–2007). The kidneys were divided into two groups: group 1 represents the treated kidneys and group 2 the contralateral (untreated) kidneys. Additionally each slice of all kidneys was divided in 3 ROIs (lower, middle and upper third) covering the complete renal parenchyma (cortex and medulla) excluding the collecting system as well as the large vessels in the renal sinus (Fig. 1b).

2.3. Doppler US measurements

Doppler US was done before and after ESWL using a curved array transducer operating a frequency from 2 to 6.0 MHz connected to an Acuson SEQUOIA 512 US scanner (Siemens Medical, Mountain View, CA, USA).

RI was measured in the interlobar or arcuate arteries in the treated and untreated kidneys. Three measures were registered for the upper, middle and lower parts of each kidney, and the mean of these measures was calculated. The US examiner was blinded to the results of MR imaging.

2.4. Statistical analysis

The data were tested for normal distribution with Kolgomorov–Smirnov test. In case of normal distribution, paramet-