European Journal of Radiology 76 (2010) 124–128

Contents lists available at ScienceDirect

European Journal of Radiology

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

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

Mohamed Abd Ellah[a,*], Christian Kremser[a,1], Leo Pallwein[a,2], Friedrich Aigner[a,3], Michael Schocke[a,4], Reinhard Peschel[b,5], Florian Pedross[c,6], Germar-Michael Pinggera[b,7], Christian Wolf[a,8], Mostafa A.M. Alsharkawy[d,9], Werner Jaschke[a,10], Ferdinand Frauscher[a,11]

[a] Innsbruck Medical University, Radiology Dept., Anich St. 35, 6020 Innsbruck, Austria
[b] Innsbruck Medical University, Urology Dept., Anich St. 35, 6020 Innsbruck, Austria
[c] Innsbruck Medical University, Medical Statistics Dept., Anich St. 35, 6020 Innsbruck, Austria
[d] Assiut University, Radiology Dept., Assiut, Egypt

ARTICLE INFO

Article history:
Received 21 October 2008
Accepted 11 May 2009

Keywords:
ESWL (extracorporeal shock wave lithotripsy)
Renal blood flow
MRI
Ultrasound
Contrast agents
Doppler ultrasound

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

* Corresponding author. Tel.: +43 512 504 24202, 6765753783 (mobile); fax: +43 512 504 24209.
E-mail addresses: dr_m_hamdy2006@hotmail.com (M.A. Ellah), christian.kremser@i-med.ac.at (C. Kremser), leo.pallwein-prettner@uki.at (L. Pallwein), friedrich.Aigner@uki.at (F. Aigner), michael.schocke@i-med.ac.at (M. Schocke), reinhard.peschel@uki.at (R. Peschel), florian.pedross@i-med.ac.at (F. Pedross), germar.pinggera@uki.at (G.-M. Pinggera), christian.wolf@bkh-reutte.at (C. Wolf), drmostafamri@yahoo.com (M.A.M. Alsharkawy), werner.jaschke@i-med.ac.at (W. Jaschke), ferdinand.frauscher@uki.at (F. Frauscher).
[1] Tel.: +43 512 504 81593.
[2] Tel.: +43 512 504 81927.
[3] Tel.: +43 512 504 82091.
[4] Tel.: +43 512 504 80926.
[5] Tel.: +43 512 504 81661.
[6] Tel.: +43 512 9003 70903.
[7] Tel.: +43 512 504 81514.
[8] Tel.: +43 5672 601 372.
[9] Tel.: +2 0123971443.
[10] Tel.: +43 512 504 22760.
[11] Tel.: +43 512 504 81545.

0720-048X/$ – see front matter © 2009 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.ejrad.2009.05.016

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-

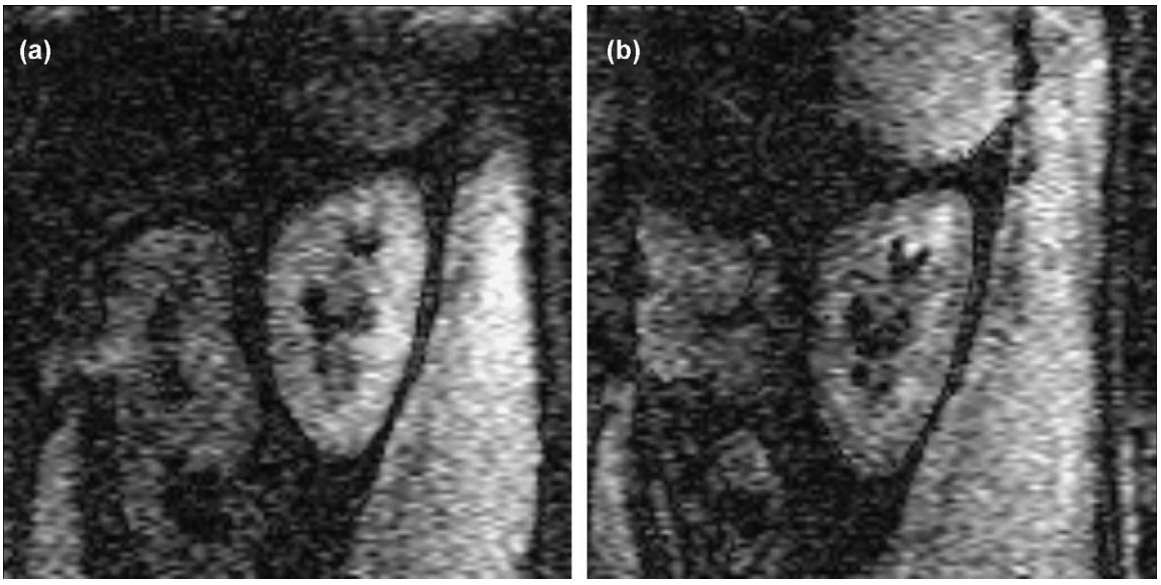

Fig. 1. Resulting FLASH STAR images after subtraction of images without and with inflow inversion. (a) Before ESWL treatment, and (b) after ESWL treatment. A reduction of FLASH–STAR values after treatment is clearly seen.

Table 1
Changes of resistive index (RI) of treated and untreated kidneys as evaluated by Doppler ultrasound.

Kidneys	Examined part	Mean RI (before ESWL)	Mean RI (after ESWL)	*p*-Values
Untreated kidneys	Middle part	0.63 ± 0.05	0.71 ± 0.05	$p < 0.001$
	Upper part	0.64 ± 0.06	0.72 ± 0.05	$p < 0.001$
	Lower part	0.65 ± 0.06	0.72 ± 0.05	$p < 0.001$
Treated kidneys				
	Middle part	0.64 ± 0.07	0.73 ± 0.06	$p < 0.001$
	Upper part	0.65 ± 0.06	0.71 ± 0.05	$p < 0.001$
	Lower part	0.65 ± 0.06	0.72 ± 0.05	$p < 0.001$

The significance of the differences in RI before and after ESWL was evaluated with the help of the Student's paired *t*-test.

ric tests were used otherwise non-parametric tests. Differences in FLASH–STAR data, DCE perfusion data and RI before and after ESWL were evaluated with a Student's paired *t*-test or a Wilcoxon test. All reported *p*-values were 2-sided and type I error level of 5% was used. Calculations were performed by using SPSS (version 15.0) software. A *p*-value of less than 0.05 was considered statistically significant.

3. Results

3.1. Resistive index

We found a significant ($p < 0.001$) increase of mean RI from 0.64 (±0.01 S.D.) to 0.72 (±0.01 S.D.) in all parts of treated kidneys after ESWL (Table 1).

The untreated kidneys showed also a significant ($p < 0.001$) increase of mean RI also from 0.64 (±0.01 S.D.) to 0.72 (±0.01 S.D.) after ESWL (Table 1).

3.2. Arterial spin labeling MR imaging

We found in the treated kidneys a significant reduction ($p = 0.001$) in the FLASH–STAR values in the upper, middle and lower poles from 64.3 (±3.5 S.D.) to 51.9 (±6.1 S.D.) after ESWL (Table 2, Fig. 1).

The untreated kidneys showed also a significant ($p = 0.001$) decrease of the FLASH–STAR values from 59.2 (±1.6 S.D.) to 51.6 (±1.7 S.D.) too.

3.3. Dynamic contrast enhanced MR imaging

The uncorrected T1 values showed a significant change after ESWL in the initial slope of the contrast media uptake curves, while the corrected T1 values showed no significant change ($p > 0.05$) (Table 3) in the initial slope of the contrast media uptake curves. This was found in the different parts of the treated kidneys (Fig. 2).

Table 2
Presentation of mean values of treated and untreated kidneys as evaluated by FLASH–STAR sequence.

Kidneys	Examined part	Mean FLASH–STAR values (before ESWL)	Mean FLASH–STAR values (after ESWL)	*p*-Values
Untreated kidneys	Middle part	59.1 ± 7.9	51.2 ± 7.6	$p < 0.001$
	Upper part	60.8 ± 7.1	53.4 ± 8.7	$p = 0.005$
	Lower part	57.6 ± 7.6	50.1 ± 7.3	$p = 0.002$
Treated kidneys	Middle part	63.2 ± 9.2	49.3 ± 6.2	$p < 0.001$
	Upper part	68.2 ± 9.5	58.8 ± 9.2	$p = 0.007$
	Lower part	61.4 ± 7.6	47.5 ± 5.2	$p < 0.001$

The significance of the differences in the values before and after ESWL was evaluated with the help of the Student's paired *t*-test.

Table 3
Presentation of rRBF (mean values) of treated and untreated kidneys as evaluated by contrast MR perfusion.

Kidneys	Examined part	Mean rRBF (before ESWL) ($\times 10^{-3}$)	Mean rRBF (after ESWL) ($\times 10^{-3}$)	p-Values
Untreated kidneys	Middle part	15.76 ± 3.83	30.97 ± 43.55	$p = 0.155$
	Upper part	25.98 ± 24.13	22.59 ± 19.33	$p = 0.790$
	Lower part	14.6 ± 5.1	14.26 ± 3.38	$p = 0.894$
Treated kidneys	Middle part	17.99 ± 10.82	16.25 ± 5.68	$p = 0.799$
	Upper part	19.47 ± 8.56	28.57 ± 35.5	$p = 0.878$
	Lower part	11.81 ± 3.45	14.91 ± 8.63	$p = 0.624$

The significance of the differences in RBF before and after ESWL was evaluated with the help of the Wilcoxon-test.

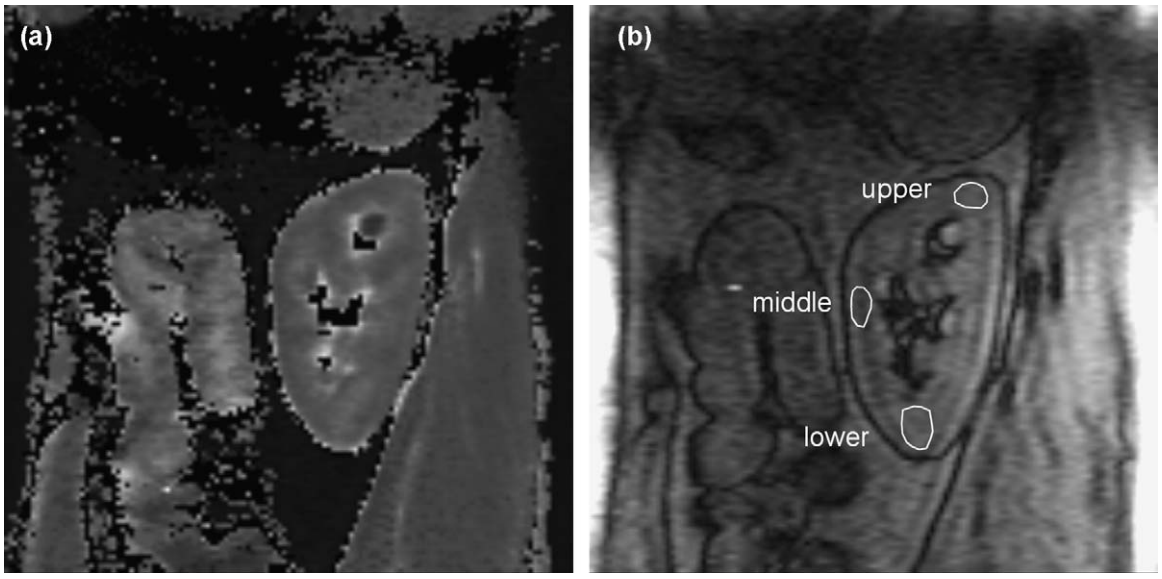

Fig. 2. (a) Typical T1-map obtained for the investigated kidneys. T1-values from identical ROI's as used for the saturation recovery images were used to calculate CA concentration time curves from the saturation recovery data. (b) Each slice of all kidneys was divided into 3 ROIs (lower, middle and upper) covering the complete renal parenchyma (cortex and medulla) excluding the collecting system as well as the large vessels in the renal sinus.

The same finding was also observed in the untreated kidneys in all parts too (Table 4).

4. Discussion

Although ESWL is considered a safe and effective treatment for upper urinary stone disease, it can cause complications, since during treatment the shock waves have definite bioeffects on the renal parenchyma. Previous studies have examined the morphologic and functional changes following ESWL in addition to the potentiating causes and possible protective measures, with most investigators have demonstrated quick resolution of these changes [15,16]. However the degree of tissue impairment caused by shock waves is still under clinical and pathophysiological investigations.

Table 4
The significance of changes in renal perfusion in the three different parts of both kidneys as evaluated by the three different methods.

Kidneys	Examined part	p-Values		
		RI	FLASH–STAR	Contrast perfusion
Untreated kidneys	Middle part	$p < 0.001$	$p < 0.001$	$p = 0.155$
	Upper part	$p < 0.001$	$p = 0.005$	$p = 0.790$
	Lower part	$p < 0.001$	$p = 0.002$	$p = 0.894$
Treated kidneys	Middle part	$p < 0.001$	$p < 0.001$	$p = 0.799$
	Upper part	$p < 0.001$	$p = 0.007$	$p = 0.878$
	Lower part	$p < 0.001$	$p < 0.001$	$p = 0.624$

Lingeman et al. and other groups reported different kinds of tissue damage depending on the number and strength of shock waves [2,17,18]. They found impairment of the renal vessels in the interlobar, arcuate and interlobular branches. Furthermore histologically proven damage of the glomeruli and tubules, interstitial edema and acute inflammatory processes leading to long-term decrease of renal function has been described. In elderly this impairment may cause new-onset of renovascular hypertension.

Knapp et al. [2] proposed a non-invasive method for determination of changes of renal vascularisation after ESWL using color Doppler US. They described an increase in RI especially in elderly (>60 years). A possible explanation for this elevation of RI may be an increased tissue pressure due to edema and a vasoconstrictive effect of substances like renin and/or endothelin. Nazaroglu et al. [19] found in patients with renal stones a temporary increase in RI in the hours following ESWL in both the ipsilateral and contralateral kidneys, which was highest in the region near the stones and lowest in the contralateral kidney. Though these results are in line with our findings in RI.

DCE MR imaging following contrast medium injection has been successfully used to observe first pass tissue perfusion of the kidney [20]. A promising technique has recently become feasible: perfusion imaging with ASL MR imaging, which uses the water spins of blood as an endogenous tracer, so it is considered a completely non-invasive method as it does not need a contrast agent [21].

Aiming to study the post-ESWL treatment changes of the kidney we combined both DCE-MR imaging and ASL MR imaging in addition to the measurement of the RI in a trial to assess hemodynamic and perfusion changes of the kidney and to study the capability

of the MR imaging to assess possible changes. We found a significant reduction in the FLASH STAR signals before and after ESWL in both kidneys. We believe that this could be caused by a reduction of blood volume due to spasm of parenchymal vessels, which occurred as a result of the tissue edema and the release of vasoactive substances including renin and endothelin. This assumption seems to be supported by the simultaneous observation of this finding in both kidneys together with the significant increase of RI after ESWL.

A significant reduction of signal intensities after ESWL was found for the FLASH–STAR measurements and has never been used before, to the best of our knowledge. During the FLASH–STAR measurement basically the inflow of blood, which was magnetically labeled proximal to the imaging plane, is observed. FLASH–STAR signals thus depend on blood flow and in addition on blood volume which both determine the time it takes until labeled blood reaches the imaging plane. Thus our FLASH–STAR results may better represent the mean transit time of the blood flow. Since our DCE MR imaging measurement suggests that ESWL does not result in significant changes of blood flow, we infer that the observed FLASH–STAR signal decrease is due to a decrease of blood volume due to vasoconstriction which is in accordance with the obtained RI data.

Measuring the initial slope of contrast agent uptake without correction of T1 values, we observed significant differences before and after therapy comparable with the findings of Mostfavi et al. [15] and Chan et al. [22]. However, after correcting for native T1-values, no significant changes due to treatment were observed in both kidneys. Thereby, the initial slope of contrast media uptake corresponds to tissue perfusion [22], so that our results suggest that ESWL may not result in alterations of renal tissue perfusion. This finding is in contradiction to previous results of e.g. Mostfavi et al. [15], which showed an increase in the medullary and a decrease in the cortical blood flow after ESWL using MR imaging. In this work, however, no correction for native T1-values to their DCE uptake curves was performed, which is in contrast to our approach, and might explain the different findings.

As already pointed out by Hittmair et al. [23] and Gowland et al. [24] it is not possible to determine relaxation rate changes from observed relative signal changes induced by the contrast medium without the knowledge of the native tissue relaxation parameters. So we suspect that the observations made by the previous two studies mainly reflect T1 changes in renal tissue, probably due to edema induced by ESWL treatment in renal tissue.

A major limitation of our study is the small number of patients studied, which limits the value of our results. Further studies with a higher number of patients investigated are desirable. Another limitation is the operator dependency of the RI measurement, and we do not have data about intra- and inter-observer variability.

5. Conclusion

We found significant changes in RI and ASL MR imaging after ESWL. In comparison DCE MR imaging showed no significant changes after ESWL. Therefore ASL MR imaging and RI seem to enable a non-invasive assessment of renal vasculature in patients undergoing ESWL. However the clinical relevance of our findings should be evaluated in further studies.

Conflict of interest

There is no conflict of interest in this work.

References

[1] Evan AP, Willis LR, Connors B, Reed G, McAteer JA, Lingeman JE. Shock wave lithotripsy-induced renal injury. Am J Kidney Dis 1991;17(4):445–50.
[2] Knapp R, Frauscher F, Helweg G, et al. Age-related changes in resistive index following extracorporeal shock wave lithotripsy. J Urol 1995;154(3):955–8.
[3] Frauscher F, Helweg G, Janetschek G, et al. Age-related incidence of hypertension following ESWL: long-term follow-up. Proc ECR 1999;80.
[4] Sarica K, Sari I, Balat A, et al. Evaluation of adrenomedullin levels in renal parenchyma subjected to extracorporeal shockwave lithotripsy. Urol Res 2003;31(4):267–71.
[5] Tublin ME, Bude RO, Platt JF. Review. The resistive index in renal Doppler sonography: where do we stand? AJR Am J Roentgenol 2003;180(4):885–92.
[6] Bude RO, Rubin JM. Relationship between the resistive index and vascular compliance and resistance. Radiology 1999;211(2):411–7.
[7] Calamante F, Williams SR, van BN, Kwong KK, Turner R. A model for quantification of perfusion in pulsed labelling techniques. NMR Biomed 1996;9(2):79–83.
[8] Edelman RR, Siewert B, Darby DG, et al. Qualitative mapping of cerebral blood flow and functional localization with echo-planar MR imaging and signal targeting with alternating radio frequency. Radiology 1994;192(2):513–20.
[9] Carlier PG, Bertoldi D, Baligand C, Wary C, Fromes Y. Muscle blood flow and oxygenation measured by NMR imaging and spectroscopy. NMR Biomed 2006;19(7):954–67.
[10] Detre JA, Williams DS, Zhang W, Roberts DA, Leigh JS, Koretsky AP. Noninvasive perfusion MR imaging using spin labelling of arterial water. In: LeBihan D, editor. Diffusion and perfusion magnetic resonance imaging. Applications to functional MRI. Raven Press; 1995. p. 296–305.
[11] Michaely HJ, Kramer H, Oesingmann N, Lodemann KP, Reiser MF, Schoenberg SO. Semiquantitative assessment of first-pass renal perfusion at 1.5 T: comparison of 2D saturation recovery sequences with and without parallel imaging. AJR Am J Roentgenol 2007;188(4):919–26.
[12] Michoux N, Montet X, Pechere A, et al. Parametric and quantitative analysis of MR renographic curves for assessing the functional behaviour of the kidney. Eur J Radiol 2005;54(1):124–35.
[13] Haase A, Matthaei D, Bartkowski R, Duhmke E, Leibfritz D. Inversion recovery snapshot FLASH MR imaging. J Comput Assist Tomogr 1989;13(6):1036–40.
[14] Kremser C, Trieb T, Rudisch A, Judmaier W, de VA. Dynamic T(1) mapping predicts outcome of chemoradiation therapy in primary rectal carcinoma: sequence implementation and data analysis. J Magn Reson Imag 2007;26(3):662–71.
[15] Mostafavi MR, Chavez DR, Cannillo J, Saltzman B, Prasad PV. Redistribution of renal blood flow after SWL evaluated by Gd-DTPA-enhanced magnetic resonance imaging. J Endourol 1998;12(1):9–12.
[16] Evan AP, Connors BA, Pennington DJ, et al. Renal disease potentiates the injury caused by SWL. J Endourol 1999;13(9):619–28.
[17] Lingeman JE, Woods J, Toth PD, Evan AP, McAteer JA. The role of lithotripsy and its side effects. J Urol 1989;141(3 Pt. 2):793–7.
[18] Esen AA, Gezer S, Gemalmaz A, Kirkali G, Kirkali Z. Effect of extracorporeal shockwave lithotripsy on plasma and urine endothelin concentrations. J Endourol 1996;10(4):325–7.
[19] Nazaroglu H, Akay AF, Bukte Y, Sahin H, Akkus Z, Bilici A. Effects of extracorporeal shock-wave lithotripsy on intrarenal resistive index. Scand J Urol Nephrol 2003;37(5):408–12.
[20] Vallee JP, Lazeyras F, Khan HG, Terrier F. Absolute renal blood flow quantification by dynamic MRI and Gd-DTPA. Eur Radiol 2000;10(8):1245–52.
[21] Karger N, Biederer J, Lusse S, et al. Quantitation of renal perfusion using arterial spin labeling with FAIR-UFLARE. Magn Reson Imag 2000;18(6):641–7.
[22] Chan AJ, Prasad PV, Priatna A, Mostafavai MR, Sunduram C, Saltzman B. Protective effect of aminophylline on renal perfusion changes induced by high-energy shockwaves identified by Gd-DTPA-enhanced first-pass perfusion MRI. J Endourol 2000;14(2):117–21.
[23] Hittmair K, Gomiscek G, Langenberger K, Recht M, Imhof H, Kramer J. Method for the quantitative assessment of contrast agent uptake in dynamic contrast-enhanced MRI. Magn Reson Med 1994;31(5):567–71.
[24] Gowland P, Mansfield P, Bullock P, Stehling M, Worthington B, Firth J. Dynamic studies of gadolinium uptake in brain tumors using inversion-recovery echo-planar imaging. Magn Reson Med 1992;26(2):241–58.