MRI Assessment of Renal Function During Percutaneous Transluminal Angioplasty of Renal Artery Stenosis in Swine

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Introduction

The purpose of our study was to test the hypothesis that MRI can successfully detect changes in renal function at the time of renal percutaneous transluminal angioplasty (PTA) in a swine model of renal artery stenosis (RAS). Renal function was assessed using the quantitative measures of extraction fraction (EF), renal blood flow (RBF), and glomerular filtration rate (GFR).

Materials and Methods

A unilateral RAS was surgically induced in six pigs using cable ties (1) on either the right or left renal artery. One to two weeks after cable tie placement, the animals were transferred to our adjacent X-ray digital subtraction angiography (DSA) and MRI suites where the following protocol was performed: 1) baseline X-ray DSA to demonstrate the RAS; 2) transfer to MRI and pre-PTA MRI to obtain baseline renal anatomic and functional measurements; 3) transfer back to X-ray DSA and therapeutic PTA of RAS; and 4) transfer back to MRI for post-PTA MRI.

Specifically, for the MRI protocol images were acquired on a whole body 3.0 T MR scanner (Trio, Siemens Medical Solutions, Erlangen, Germany) with an 8-channel cardiac array coil. Following localization scans, a coronal 3D time-resolved intraarterial contrast-enhanced MR angiogram of the abdomen was acquired to precisely define vessel positions (1.1 × 1.1 × 4.2 mm voxels, 280 × 280 × 50 mm FOV, 256 × 256 × 20 matrix, 3.0 s/frame, TR/TE = 3.61/1.11 ms, 25º flip angle, 560 Hz/px, 6/8 in-plane and through-plane phase encoding partial Fourier, 2× in-plane GRAPPA (2) with 24 reference lines, 3 TRICKS (3) segments). We injected 40 ml of an 8% gadolinium (Gd)-based contrast agent solution (Magnevist, Berlex, Wayne, New Jersey) through the abdominal aorta catheter at 6 ml/s using a power injector. Based on the arterial and venous phases of the angiogram, the slice position for the flow quantification and T1 mapping scans on a given side was prescribed such that it was 1) perpendicular to the renal artery, 2) included the ipsilateral renal vein, and 3) was proximal to any stenosis. Flow quantification and T1 mapping scans were performed on both the left and right sides; these scans provided images for the calculation of RBF and EF, respectively. A 2D phase-contrast sequence was used to quantify flow (4) (2.5 × 3.1 × 5.0 mm voxels, 320 × 160 mm FOV, 128 × 51 matrix, TR/TE = 95/3.2 ms, 30º flip angle, 400 Hz/px, 6 averages, 25 phases, 7 segments, 80 cm/s velocity encoding). A Look-Locker echo planar imaging (EPI) sequence (5) was used for T1 mapping (2.5 × 2.5 × 5.0 mm, 320 × 160 mm FOV, 128 × 64 matrix, TR/TE = 23/11 ms, 20º flip angle, 1220 Hz/px, 0.98 ms echo spacing, 120 phases).

EF was calculated from T1 measurements in the renal artery and vein (6-9):

$$\mathrm{EF} = \frac{1/T_1^a - 1/T_1^v}{1/T_1^a - 1/T_1^0}, \qquad [1]$$

where "a" and "v" superscripts refer to artery and vein, respectively, and "0" refers to the T1 measured in the absence of Gd. Single kidney GFR can then be calculated as EF × RBF × (1 - Hct).

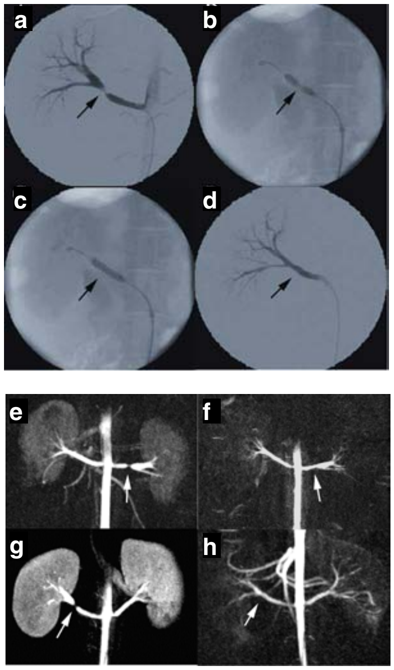

Figure 1. X-ray angiograms (**a**) before PTA, (**b**) before and (**c**) after inflating balloon catheter, and (**d**) after PTA. MR angiograms (**e**,**g**) before PTA and (**f**,**h**) after PTA. Arrows indicate site of stenosis.

Results

Stenosis was successfully induced in all animals. Figure 1 shows typical X-ray and MR angiograms before, during, and after the PTA. Using the intraarterial time-resolved MRA technique, an arterial phase image without venous contamination was consistently acquired without the need for timing the arrival of contrast. Figure 2 summarizes the EF measurements in all pigs. Pre-/post-PTA EF mean ± standard deviation values were 0.10 ± 0.033/0.19 ± 0.056, and the change was statistically significant (p = 0.031). Pre-/post-PTA RBF values were 4.4 ± 3.0/5.2 ± 4.2 ml/min, and the change was not statistically significant (p = 0.44). Pre-/post-PTA single kidney GFR values were 19 ± 14/40 ± 33 ml/min, and the change was statistically significant (p = 0.031).

Discussion

While investigators have previously shown that EF, RBF, and GFR can be measured noninvasively with MRI (5-9), this study demonstrates for the first time that these measures can be used to document a change in renal function immediately following PTA. With the advent of hybrid X-ray/MR interventional suites, the ability to perform such functional measures in a clinical setting is now possible. Changes in both EF and GFR were found to be statistically significant while the change in RBF was not. The lack of change in RBF could possibly be explained by the kidneys' ability to regulate RBF.

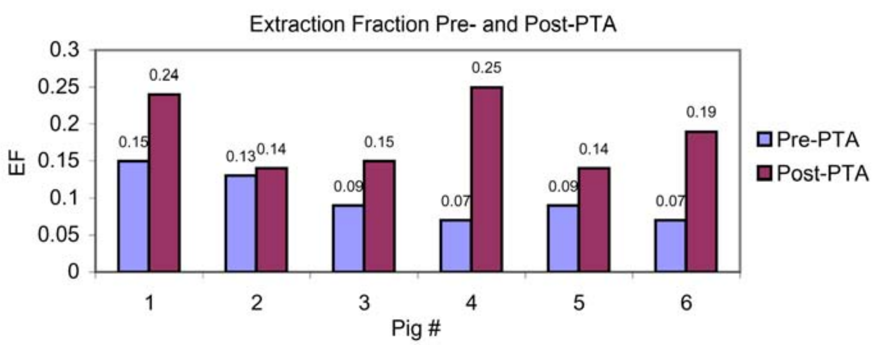

Figure 2. Extraction fraction (EF) measurements in each pig before and after PTA. Pre-/post-PTA EF mean ± standard deviation values were 0.10 ± 0.033/0.19 ± 0.056.

References

1. Yang X, et al. J Vasc Interv Radiol 1998;9:953-959.
2. Griswold MA, et al. MRM 2002;47:1202-1210.
3. Korosec FR, et al. MRM 1996;36:345-351.
4. Schoenberg SO, et al. Radiology 1997;203:45-53.
5. Niendorf ER, et al. MRM 1996;36:571-578.
6. Dumoulin CL, et al. MRM 1994;32:370-378.
7. Niendorf ER, et al. Radiology 1998;206:791-798.
8. Katzberg RW. Radiology 1999;210:287-288.
9. Levin YS, et al. MRM 2005;54:309-316.