Image Guided and Monitored Renal Artery Stenting Using Only MRI

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Introduction: This work represents a first study in which MRI is used exclusively throughout guidewire and catheter insertion, stent deployment, and confirmation of therapeutic success in renal artery stenting, a clinically important cardiovascular procedure. This work demonstrates the ability of a unique interventional MR system to be used safely and effectively as the only imaging modality for all phases of an MR guided stent-supported angioplasty in a porcine animal model with experimentally induced renal stenosis. The presented interventional MR system employs our previously reported tools for real-time catheter tracking with automated scan plane positioning [1], adaptive image parameters [2], and radial True-FISP imaging coupled with a high speed reconstruction technique [3].

Materials and Methods: A fibrotic plaque was created through intravascular RF ablation in the left and right renal artery of six healthy farm pigs with an average body weight of 75 kg. The pigs were anesthetized, and the interventional MR system (**fig 1**: Siemens 1.5T Sonata, Erlangen Germany) was used to facilitate the stent-supported renal angioplasty at the site of the stenosis. All animal procedures were approved by our Institutional Animal Care and Use Committee. A pre-operative MR angiogram (MRA) was collected to localize the stenosis and to serve as a roadmap during the procedure. A standard 5 French angiographic catheter (Torcon NB Advantage Angiographic Catheter, Cook, Bloomington, IN, USA) and 5 French balloon catheter (OmniFlex, Angio Dynamics, Queensbury, NY, USA) were both instrumented with tuned and capacitively coupled active tracking markers. The angiographic catheter and a hydrophilic-coated Nitenol guidewire (0.035-inch Radifocus, Terumo, Tokyo, Japan) were advanced co-axially through the abdominal aorta and into the renal artery under real-time imaging guidance using a radial True-FISP sequence (TR/TE=4.43/2.22ms, FA=70^{o}, ST=5mm, BW/Px=399Hz/Px, FOV=[300x300mm to 100x100mm], radial lines per image=[128 to 96]). During this phase of the procedure, the adaptive imaging automatically adjusted the number of radial interleaves collected per image (**fig 2a**). Once the angiographic catheter tip was positioned in the renal artery, the angiographic catheter was withdrawn, leaving the guidewire in its place. The balloon catheter, with a Palmaz P204 Balloon Expandable Intraluminal stent (Johnson & Johnson, Warren, NJ, USA) mounted on the balloon, was then advanced along the guidewire; during this phase of the procedure, the adaptive imaging automatically adjusted the FOV and image resolution (**fig 2b**) in response to the catheter insertion speed. Post-operative MR images were used to instantly assess the success of the procedure; subsequent X-Ray angiography (**fig 3**) was used to evaluate the accuracy of the MR results. Finally, the time required for the MR guided stent deployment was compared to reported durations required for identical procedures performed under X-Ray Fluoroscopy.

Results: All of the stent-supported angioplasty interventions were a technical success and performed without complications. The disease model used for this work produced a fibrotic plaque that reduced the renal artery lumen diameter by an average of 53.6%. The average post-operative residual stenosis was found to be 14.9%. The pre- and post-operative stenosis were accurately depicted in the MR images and MRA; this was confirmed using pre- and post-operative x-ray angiograms in which the size of the stenosis were found to be within 1.3% of the MR estimates. The average distance between the center of the renal stenosis (i.e. the narrowest part of the plaque) and the center of the deployed stent was 0.98±0.69 mm. Additionally, using this interventional MRI system to guide renal artery stenting significantly reduced the procedure duration, relative to using x-ray fluoroscopy; while x-ray-based intervention often requires up to 45 minutes, an average of only 25 minutes was needed when using MR guidance in this trial. This reduction in procedure duration was primarily realized because a 3D MRA was used for pre-operative planning instead of a 2D projection x-ray angiography.

Conclusions: This study has demonstrated the first successful treatment of stent supported renal angioplasty in an experimental animal model under exclusively MRI guidance and monitoring. The presented interventional MR platform provides the interventionalist with all image data necessary to first, guide a catheter to an anatomical target with sufficient accuracy for clinical applications (2D images with adaptable temporal resolution that follow the catheter tip and a roadmap that indicates the catheter's position within the vascular tree), and second, to monitor the delivery therapy (image parameters automatically adjust their values once the catheter reaches the anatomical target). In contrast to the way in which MR scanners operate during general diagnostic imaging, this platform provides an MR system interface that is customized for interventional procedures; manual adjustment of scan plane position and/or specific image parameter values is not required during the procedure. Therefore, this work represents a important milestone in demonstrating an integrated system for MR guided cardiovascular intervention.

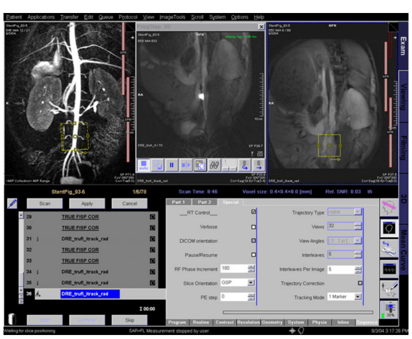
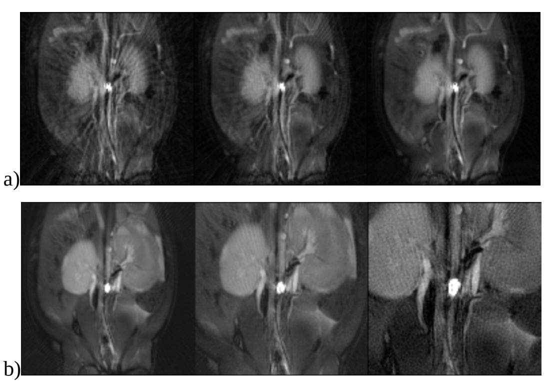


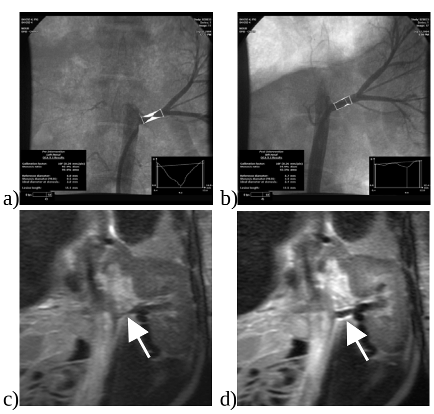
Figure 1: The interventional interface is displayed on both the host computer and the in-room monitor. Three image types appear simultaneously: An MRA in which renal stenoses are clearly visible (left), the real-time 2D images that follow the catheter and react to changes in insertion speed (center), and a static 2D image (right). The catheter tip and real-time image slice's current location are indicated on the MRA and static image.

a)



b)

Figure 2: Selected sequential stills acquired during catheterization of renal arteries and stent deployment. During catheterization, (a) the adaptive image parameter software responded to the catheter's decrease in speed by reducing temporal resolution and improving SNR and image quality. During stent deployment, (b) the adaptive image parameter software responded to the catheter's decrease in speed by decreasing the FOV and improving image resolution.



a) b) c) d)

Figure 3: (a) Pre- and (b) post-operative X-ray angiograms of a pig with stenosis in the left renal artery. The bright regions in the vessel are graphical overlays added by image analysis tools provided by the vendor. Corresponding (c) pre- and (d) post-operative MR HASTE images.

References:

[1] C Flask, *et al*. JMRI **14**, 617-627(2001), **[2]** D Elgort, *et al*. JMRI **18**, 621–626 (2003), **[3]** B Dale, *et al*. IEEE Trans Med Imaging **20**(3), 207-17 (2001)