Non-invasive Assessment of Transstenotic Pressure Gradients Utilizing 3D Phase Contrast MRA: Validation against Endovascular Pressure Measurements in a Porcine Study

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Introduction

Renal artery stenosis (RAS) is an important cause of hypertension and progressive renal insufficiency occuring in up to 45% of patients with peripheral vascular disease (1). Patients often undergo percutaneous transluminal angioplasty or stenting if a renal artery is found to have a hemodynamically significant stenosis (≥75%). In cases of a mild stenosis (less than 50%), no intervention is typically pursued. However, the hemodynamic significance of a stenosis measured as 50-75% is difficult to derive from vessel diameter measurements alone. In such cases, intraarterial pressure measurements are obtained under X-ray angiography (2). In a recent study, the feasibility of non-invasive assessment of transstenotic pressure gradients (TSPG) has been successfully shown in the carotid and iliac arteries utilizing phase contrast with vastly under sampled isotropic projection reconstruction (PC VIPR) (3, 4). However, this technique has failed for the assessment of renal artery stenoses due to the lack of respiratory motion compensation(4). The purpose of this study was to evaluate TSPG measurements in RAS utilizing a novel respiratory gated PC VIPR approach in a swine study.

Methods

Following Animal Care and Use Committee protocol approval, bilateral RAS was created surgically in 12 swine. All studies were performed under general anesthesia. MRA of the renal arteries were performed on a clinical 1.5 T Scanner (Signa HD, GE Healthcare, Waukesha, WI, USA). The PC VIPR sequence (dual echo, 18,000 projection angles, 10° flip, TR/TE (first echo) = 11.4/3.7 msec, BW = ±62.5kHz, imaging volume: 260x260x160 mm^3, true isotropic spatial resolution: 1.0x1.0x1.0 mm^3, venc = 150cm/s, scan time 11:00 min) was performed without the use of gadolinium based contrast agents.

Fig. 1 Moderate Renal Artery Stenosis Roadmap image of the DSA (A) with two endovascular pressure sensing guidewires (light arrows in A indicate location of pressure sensors) across a moderate left renal artery stenosis (solid arrow in A). MIP (B) and streamlines reconstruction (C) of non contrast enhanced PC VIPR MRA readily reveal the stenosis (arrows in B, C) and increased velocity distal to the stenosis (light arrow in C).

Respiratory gating was performed with an adaptive gating scheme based on respiratory bellow waveforms with 50% respiratory gating efficiency (5). Pressure gradients were calculated using the Navier-Stokes equation and an iterative algorithm that has been described elsewhere (6, 7). Endovascular pressure measurements were assessed with commercially available pressure sensing guidewires (Certus Pressure Wire, RADI, Uppsala, Sweden) and used as the gold standard for quantification of the TSPG. The pressure measurements under DSA guidance and by MRI were performed back to back in an XMR Angio Suite that ensured minimum delay times between measurements (Figure 1). Pearson correlation was used for statistical comparison of the two measurements.
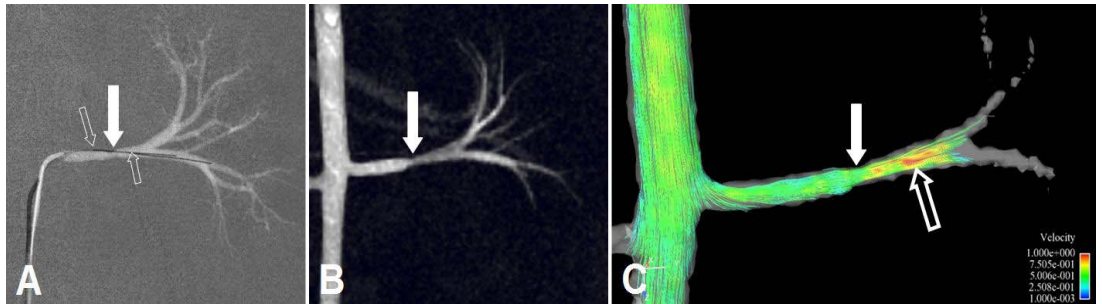
Results

DSA, endovascular pressure measurements, and PC VIPR data sets were successfully acquired in all studies. In all cases, MRA images based on complex difference data sets were created from the PC VIPR data. In 5 cases of severe RAS (mean 86%), the residual lumen within the stenosis was so small that TSPG could not be determined using PC VIPR (Figure 2) since pressure differences can only be calculated for connected regions. These lesions were excluded from the statistical analysis. However, since the MRA images derived from the PC VIPR data confirmed the presence of severe RAS in all of these cases and the renal arteries distal to the stenosis could still be visualized except in the one case of an arterial occlusion. The severity of stenosis based on visual assessment correlated well with DSA (Pearson r = 0.77). In the other 19 renal artery stenoses (mean 62%) excellent correlation between the non-invasive TSPG utilizing PC VIPR and endovascular pressure measurements was found (r = 0.977; 95% CI: 0.931, 0.998; p < 0.001).

Fig. 2 Significant Renal Artery Stenosis Selective DSA demonstrates a significant renal artery stenosis (A, TSPG = 48mmHg. Streamlines discontinue at the stenosis indicating a significant luminal narrowing (B). Please note flow signal distal to the stenosis indicating high degree stenosis but excluding occlusion.

Discussion

This study demonstrates the feasibility of PC VIPR MRA to calculate TSPG across renal artery stenoses in a swine model, thereby determining the hemodynamic significance of RAS. By combining ECG gating, respiratory motion compensation, and high spatial and temporal resolution, non-invasive calculation of TSPG in the renal arteries is now possible. In addition, this is inherently a non-contrast enhanced MRA method that does not require the use of Gadolinium based contrast agents, making it a viable alternative in patients with impaired renal function. The lack of PC VIPR TSPG data in the most severe renal artery stenoses does not pose a limitation in clinical practice because patients with severe RAS are referred for surgical treatment regardless. Proper assessment of the hemodynamic significance of *moderate* lesions is the clinical challenge that has been properly identified by PC VIPR. Therefore, the excellent correlation between TSPG measurements by PC VIPR and endovascular guidewires indicate that this technique is ready for the transition from the animal lab to clinical practice. This approach has the potential to become a major advance in the noninvasive evaluation of RAS and, as a result, in the management of renovascular hypertension.

References

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4. Lum D et al., Radiology 2007;245(3):751–760   5. Johnson KM et al., Proceedings ISMRM 2008: Abstrct. 733   6. Tyszka JM et al., JMRI 2000;12:321-329 7.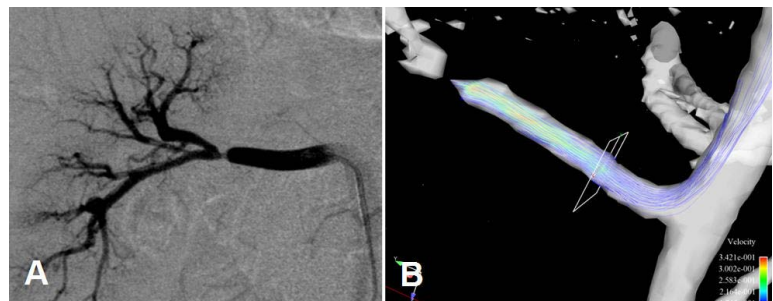 Thompson RB et al., MRM 2003;49:1056-1066