Pressure-Sensing Guidewire Analysis in RAS

Adapting this coronary-based technology to optimize "functional" renal artery revascularization could have significant clinical implications.

BY DAVID E. ALLIE, MD; CHRIS J. HEBERT, RT, RCIS; AND CRAIG M. WALKER, MD

There exists little controversy regarding the clinical benefits of renal artery (RA) PTA/stenting in hemodynamically significant renal artery stenosis (RAS) in several patient subsets, including (1) those with poorly controlled hypertension on multiple antihypertensive medications or those who are intolerant of medications; (2) patients with ischemic nephropathy for preservation of renal function in the patient demonstrating deteriorating renal function and/or renal size; or (3) patients with coronary ischemia, angina, congestive heart failure, or flash pulmonary edema exacerbated by RAS or renovascular hypertension.[1-4] Unfortunately, RA PTA/stenting has shown no objective clinical benefit in 30% to 40% of patients.[5,6]

Therefore, there is significant controversy in several other aspects of RAS treatment, including (1) the definition and identification of a hemodynamically or physiologically (functional) significant RAS; (2) treatment in unilateral or bilateral moderate (50%-70%) RAS; and (3) any treatment recommendation in RA in-stent restenosis (ISR).[5-8] Several reports have documented a decline in renal function after PTA/stenting and high ISR rates (12%-29%), further leading to controversy in treating any RAS patient.[9-12] This will continue to be true for *ad hoc* renal interventions performed during

"drive-by" cardiac catheterization until outcomes are predictable, improved, and complications minimized.[9-13]

Meticulous technique and use of distal protection devices to reduce cholesterol and atherosclerotic emboli, and contrast-induced nephrotoxicity, are important issues related to best outcomes, but there is little consensus on the optimal methods of identifying significant RAS and no consensus correlating anatomic RAS to hemodynamic or physiological (functional) revascularization in RAS.
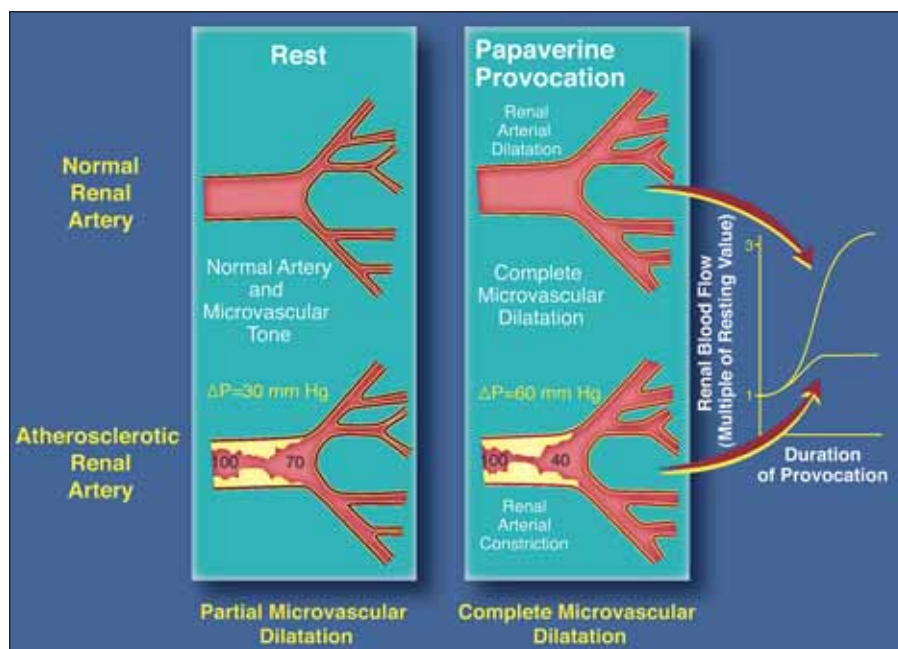

Figure 1. Regulation of blood flow in a normal and an atherosclerotic RA. In the normal RA, the vessel and microvascular vessels dilate with papaverine provocation to meet metabolic demands. In the diseased vessel, during rest, there is a drop in pressure (ΔP) across the stenosis. During provocation, the RA constricts, the ΔP across the stenosis increases, and the microcirculation has limited capacity for dilatation. The increase of blood flow is inadequate to meet the increased metabolic demands. An FFRren model would be reduced (FFRren = 0.40).

CURRENT RAS ASSESSMENT

Conventional angiography with or without digital subtraction angiography (CADSA) is still considered the "gold standard," but it is well known that CADSA has significant limitations.[14,15] Multidetector CT angiography (MDCTA) may prove to be more sensitive than CADSA in detecting anatomic RAS, but it is not widely available at this time and provides no functional information.[16] Discrete ostial lesions and complex, especially oblique, RA ostial origins are common and add to the difficulty in identifying and quantifying RAS. Patients with RA ISR are increasingly returning for evaluation and treatment, and again, there currently exists no consensus treatment or guidelines regarding diagnosis or repeat revascularization.[10,17,18]

Translesional systolic pressure gradients (TSPG) have recently been advocated by Rundback et al as a standard guideline for reporting RA revascularization in clinical trials, but limitations have been identified with TSPG determina-

tions with 4-F to 6-F end-hole catheters and the threshold values.[15,19] There is no consensus as to the exact degree of RAS or minimal TSPG justifying revascularization, and neither CADSA nor TSPG provide physiological RAS information.[14,15] Radionuclide scans, renal vein renin assays, captopril renography, and duplex ultrasound resistive index have been advocated as methods to physiologically assess RAS, but all have significant limitations. Additionally, these methods are infrequently used as physiological or functional measures of RAS and therefore are rarely used for decision making in RA revascularization.[20-22]

THE PRESSUREWIRE AND FRACTIONAL FLOW RESERVE

It is becoming increasingly incumbent upon clinicians to identify and document objective indications for treatment based on both anatomic and physiologic parameters and have data to support treatment and predict outcomes. With significant controversy still surrounding RA PTA/stent-
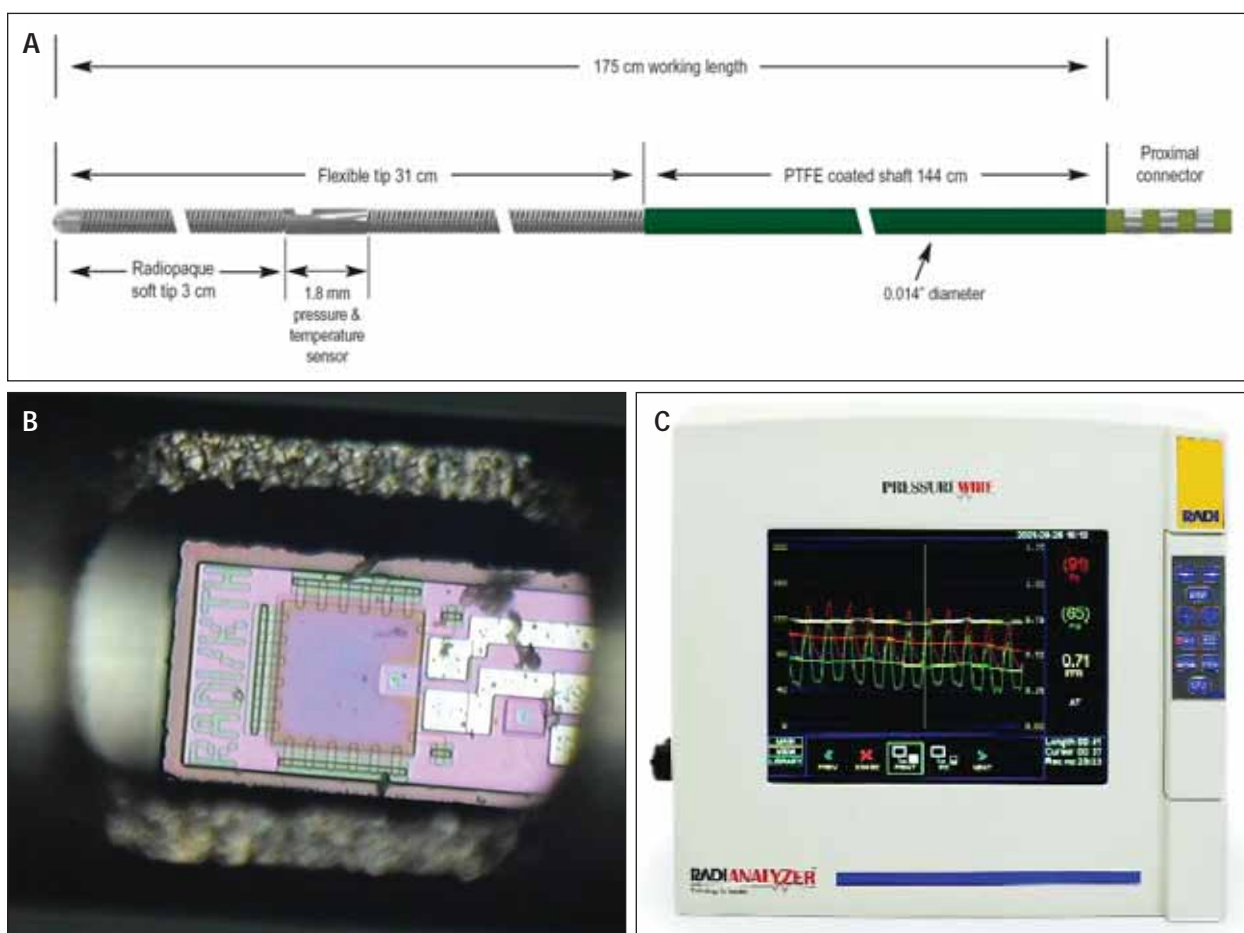

Figure 2. Schematic of the RADI PressureWire (RADI Medical Inc., Uppsla, Sweden). Note the 31-cm flexible tip and the 3-cm radiopaque soft tip distal to the 1.8-mm sensor (A). Magnification of the fiberoptic pressure sensor. The element modulates an optical reflection with pressure-induced elastic movements using an emitting diode in the control unit as a light source (B). The RADIAnalyzer demonstrating a 0.71 FFRmyo (C).
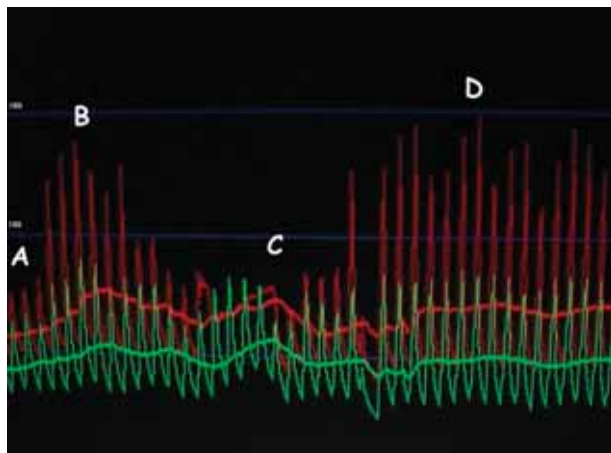
Figure 3. PressureWire TSPG analysis; the guiding catheter is engaged at the RA ostia to facilitate the PressureWire translesional placement (A). The guide catheter is pulled back into the aorta demonstrating a 30-mm Hg peak-to-peak systolic gradient (B). Re-engagement of the guide catheter into RA, avoiding crossing the lesion, followed by RA papaverine injection (C). The guide catheter is immediately pulled back into the aorta demonstrating a 70-mm Hg peak-to-peak systolic after papaverine provocation gradient (D).

ing, no other vascular territory would benefit more from a method or "tool" that would allow functional revascularization decision making than RAS, much like functional assessment for coronary artery disease in the cath lab. The PressureWire is such a tool that allows acquisition of pressure signals on a .014-inch coronary angioplasty guidewire, eliminating false gradients due to large catheters. Use of the PressureWire and physiologic measurements have been found to be beneficial in percutaneous coronary intervention (PCI) in identifying ischemic (functional) lesions, optimizing stent deployment, and in predicting and improving outcomes.[23-28] There are limited data describing the use of the PressureWire in peripheral vascular disease and no validated data reporting the utility in determining the fractional flow reserve (FFR) in RAS (FFRren).[29-32]

Reports by Pijls, Bech, DeBruyne, and Kern have eloquently described the concept of myocardial FFR (FFRmyo) as an accurate, safe, simple, cost-effective, and lesion-specific invasive index of the functional severity of a coronary artery stenosis that is not affected by the microcirculation or hemodynamic variability.[24,26-28] Using reasonable clinical assumptions, we have investigated the use of the FFR concept analogously in indexing the functional severity of RAS. The FFR is defined as the maximal blood flow in the presence of a stenosis divided by the theoretical maximum flow without a stenosis; therefore, a normal value (ratio) is 1.0. The FFR does not directly measure blood flow, but it is the transtenotic pressure across a stenosis measured at peak

blood flow after administration of an arteriolar vasodilator and indexed for the aortic driving pressure. Several key concepts are that a stenotic lesion obstructs flow only if a pressure gradient develops across the stenosis with maximal hyperemic arteriolar and microvascular dilation. If there is no pressure gradient, the lesion is not the site of a functional obstruction and PTA/stenting cannot physiologically improve blood flow.

Because flow can be expressed as the ratio of aortic driving pressure to resistance ($Rmin$), maximal attainable blood flow through the end organ equals the ratio of perfusion pressure (PP) across the end organ (distal RA pressure minus renal venous pressure) and the $Rmin$. This assumption has been proven true for the heart but remains uninvestigated for the kidney. Using this analogous assumption for the kidney, if there is no RAS, the PP across the RAS/kidney equals $Pa - Pv$, where Pa = mean aortic pressure and Pv = venous pressure. In RAS, the PP across the kidney has decreased to $Pd - Pv$, where Pd = hyperemic RA pressure distal to the lesion. Therefore,

$$FFR = \frac{(Pd - Pv)\ Rmin}{(Pa - Pv)\ Rmin}$$

and, because at maximum RA vasodilation, R is constant and minimal, the $Rmin$ cancel resulting in:

$$FFR = \frac{(Pd - Pv)}{(Pa - Pv)}$$

Because Pv is minimal and not increased, the FFR is further simplified:

$$FFR = \frac{Pd}{Pa}$$

when Pd and Pa are measured simultaneously by a guiding catheter and pressure sensing guidewire after maximum vasodilatation (Figure 1).

THE BENEFITS OF FFR_{MYO} IN PCI: A POTENTIAL IN RAS

Multiple reports have validated the utilization of FFRmyo, including benefits in identifying functional severity of coronary stenosis, identifying ischemic culprit lesions, facilitating decision making in multivessel coronary artery disease, assessment of intermediate lesions, optimization of PCI stent deployment and outcomes, and in assessing left main disease, ostial lesions, bifurcations, and serial stenosis. Pijls et al demonstrated an FFR <0.75 (the mean pressure distal to the stenotic lesion or <75% of the mean aortic pressure) correlated with functional stenosis and inducible ischemia on exercise testing, thallium scans, and stress echocardiograms.[23] Pijls et al also showed that successful PCI in patients with FFR <0.75 relieved symptoms, improved functional class, and reversed ischemia on postprocedural functional stress testing and that PCI in intermediate lesions with FFRmyo >0.75 and worse outcomes than medical therapy
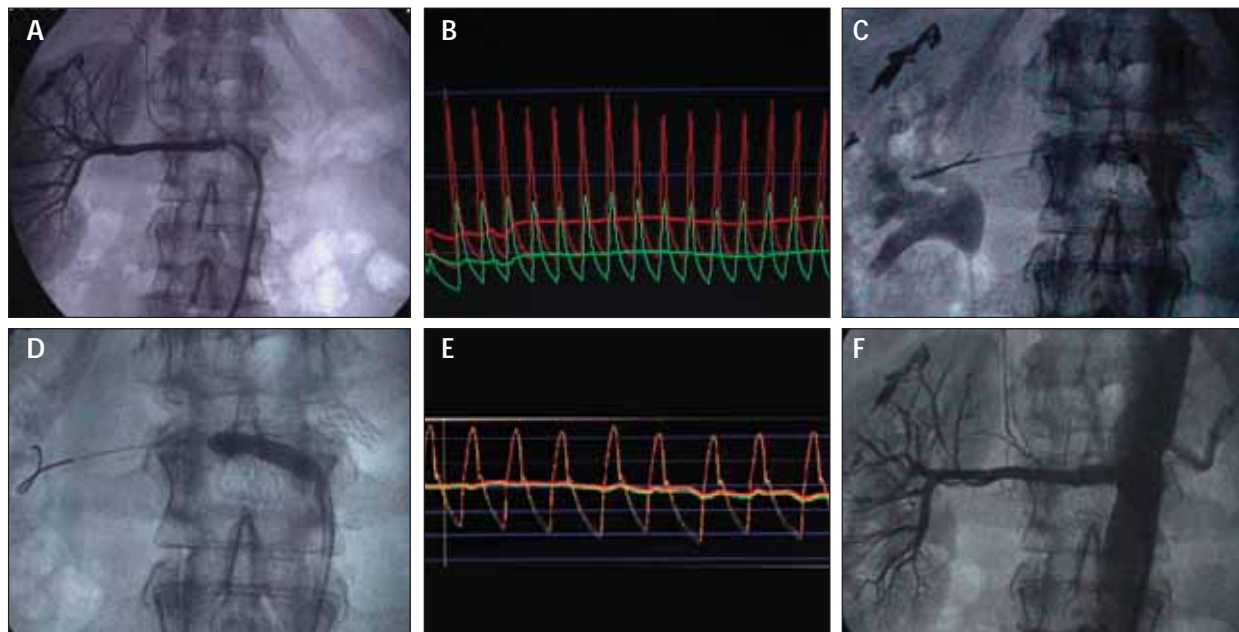
Figure 4. An RA ISR case demonstrating use of the PressureWire. An 80% to 90% right RA ISR lesion by CADSA (A). A 70-mm Hg peak-to-peak PressureWire TSPG after papaverine provocation (B). A 2-mm eccentric excimer laser probe begins 4-quadrant atheroablation (C). Low-pressure PTA after laser (D). Postlaser PTA PressureWire TSPG confirms obliteration (<5 mm Hg) of the gradient (E). Postprocedural CADSA results (F).

alone.[23]

Hanekamp et al compared quantitative coronary angiography, intravascular ultrasound (IVUS), and FFR to assess optimal PCI stent deployment in 81 patients paired with IVUS and quantitative coronary assessment.[25] A concordance was found between FFR/IVUS, IVUS/QCA, and FFR/QCA of 91%, 48%, and 46%, respectively, therefore proposing FFR as a rapid and cheaper alternative to IVUS for optimizing stent deployment and outcomes. Pijls et al analyzed FFR-facilitated, post-PCI outcomes at 6 months and found that FFR was a strong predictor of outcomes, with event rates of 4.9%, 6.2%, 20.3%, and 29.5%, in the post-PCI FFR group >0.85, 0.90 to 0.95, 0.80 to 0.90, and <0.80, respectively (P >.001).[26] In a randomized trial, Bech et al determined the appropriateness of PCI in patients with moderate coronary artery disease who did not have documented inducible ischemia and who were referred for PCI. An FFR of < or >0.75 identified those patients who benefited from PCI (<0.75 before and >0.75 after PCI) and proved patients with FFR >0.75 could be safely treated medically.[27] Utilizing the proven concepts with the PressureWire in PCI, and considering the recognized limitations with renal PTA/stent, we began a PressureWire safety and feasibility analysis in treating 89 patients with RAS. This analysis in RAS included a comparison between traditional 4-F TSPG, PressureWire-obtained TSPG, FFRren, percent stenosis by MDCTA and CADSA, and an analysis of our clinical decision making in

the cath lab based on this anatomic and functional information.

STUDY METHODOLOGY/TECHNIQUE

The .014-inch RADI PressureWire is a high-fidelity, solid-state, electronic .014-inch pressure-sensing, coronary angioplasty guidewire with wire characteristics comparable to a conventional high-torque, floppy angioplasty guidewire (Figure 2). The pressure sensor is located 3 cm proximal from the wire tip, allowing ample room for wire manipulation without requiring repeated wire tip crossing. For our RAS TSPG analysis and PressureWire functional analysis, the PressureWire is introduced through a 4-F catheter, and is calibrated and advanced into the RA. The lesion is crossed positioning the sensor distal to the stenosis. The guiding catheter tip is placed 5 mm to 10 mm into the aorta (away from the renal ostium) and the sensor tip is placed 3 mm to 5 mm distal to the lesion. A resting PressureWire TSPG is first analyzed with the signal RADI analyzer by recording the peak-to-peak systolic pressure difference between the pressure sensor located distal to the lesion and the guiding catheter tip placed well into the aorta. The 4-F guiding catheter is then placed across the lesion and a traditional pull-back, peak-to-peak systolic TSPG is recorded as the catheter is pulled back 5 mm to 10 mm into the aorta (Figure 3).

We used papaverine as our provocative (hyperemic vaso-

CRITERIA FOR RAS: FUNCTIONAL ASSESSMENT OF THE RENAL ARTERY STENOSIS

By Morton J. Kern, MD

How can one conclusively demonstrate that renal artery stenting is necessary and that the procedure is justified for its risks and clinical benefits to the patient subsets of poorly controlled hypertension despite multiple medications, stabilization of deteriorating renal function and renal size, and prevention of episodic severe pulmonary edema in patients with coexisting coronary artery disease and hypertension? Which degree of renal stenosis is important, by which measurement and, most of all, how can this approach be best quantified?

The answers to these questions spark controversy because poor results occur in 30% to 40% of patients after renal artery stenting who have no demonstrable clinical benefit. Did the procedure fail or was the procedure unnecessary? We describe the issues with regard to the definition and identification of physiologically functional significant renal artery stenosis and highlight the application of transstenotic pressure measurements and their role in identifying those renal stenoses thought to be functionally significant lesions.

The fundamental problem with all angiographic definitions of arterial lesion severity is that for an eccentric orifice (which comprise the majority of all angiographic stenoses) the two-dimensional geometry fails to translate into a representative physiologic response (ie, a severe narrowing does not always have a severe pressure gradient). This disparity between angiographic percent stenosis and true physiologic stenosis is well understood from the coronary artery literature, especially with the wide appreciation of the findings of intravascular ultrasound imaging. A large discrepancy between the angiographic percent diameter stenosis and the IVUS-identified lumen cross-sectional area has been repeatedly identified. Moreover, the physiologic importance of angiographic lesions is widely disparate as evidenced not only by stress testing results but also for hemodynamic assessments. For coronary stenoses, some severe lesions have no evidence of flow impairment by resistance or pressure gradient, whereas other more modest narrowings have a significant physiologic impact. The same issue applies to the renal artery and its attendant stenosis with angiographic difficulties arising, especially in the ostial regions of these vessels. For ostial lesions in coronary arteries, a significant variance between physiologic findings and the percent diameter stenosis is reported.

The physiology of the renal artery stenosis differs from that of coronary artery stenosis in that a significant coronary stenosis has a predominant diastolic gradient, whereas the renal artery has a systolic pressure gradient (as do all peripheral arterial stenoses). For the kidney, peak systolic pressure differences between the perfusion head in the aorta and the distal recipient bed in the kidney probably play more of a role because there is equilibration of the diastolic pressures. The differences between the mean arterial pressure values may be minimal even at maximal flow, but peak systolic perfusion pressure may be a more sensitive indicator than in the coronary bed. A modest or mild systolic translesional pressure loss may indicate a significant renal perfusion deficit. Because the physiology of the kidney differs from that of the heart in both the phasic nature of the pressure difference and in the resistance bed responses to common vasodilators, the FFR concept for the renal arteries has not yet been adequately defined. Moreover, even if the FFR concept is applied, the best hyperemic stimuli to assess the microcirculation of the renal bed remain unknown.

Finally, with regard to the best measurement of translesional gradients and the hemodynamic criteria, all previous studies have used small catheters (at least 4 F or larger). The difference between a 4-F catheter and a .014-inch pressure guidewire gradient is significant and consistent. The absence of a pressure gradient with a 4-F catheter certainly would be a pressure gradient of 0 with the guidewire, but the converse is not true. A modest or even important gradient with the 4-F catheter can also be a gradient of 0 with the .014-inch pressure wire. The use of pressure gradients based on catheter measurements has led to the assumption that treatment of renal artery stenosis with such gradients was either ineffective or unsuccessful instead of realizing that stenting a true low- or no-gradient stenosis was not necessary and thus no clinical difference would be seen or expected.

The importance of the functional assessment of renal arteries prior to revascularization will improve outcome, provide accurate assessment of the endpoint of the intervention, identify suboptimal stent deployment in some conditions, and will identify additional angiographic anomalies, which may or may not be physiologically significant. The documentation of the outcome and quantitation of the indications to treat the renal artery stenosis will provide the best clinical outcomes and reshape our current activity in this field.

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dialation) agent because it is known as a potent peripheral arterial vasodilator. To date, there are no published data using papaverine in RAS or intra-arterial RA injection. In our initial experience, we used 30 mg of papaverine because it was a familiar surgical dose used safely in the OR (internal mammary artery preparation during CABG, intra-arterial SFA, or popliteal artery injection during thromboembolectomy). Recently, we have found a 20-mg papaverine injection to be effective, and this is now our routine provocation dose for PressureWire TSPG and FFRren. The RA injection is made as a rapid hand-held 20-mg injection of papaverine in 10 mL of saline. The renal ostia is engaged with the guiding catheter, and we avoid totally crossing the lesion to minimize catheter manipulation at the ostia and lesion. The catheter is immediately pulled back into the aorta for PressureWire TSPG determination because the papaverine response occurs within 5 to 15 seconds. DeBruyne has also found 20 mg of papaverine to be equivalent to adenosine (40 µg/kg per min) for FFRmyo.[33] There was no difference in clinical response between 20 mg and 30 mg of papaverine intra-arterial injection. Mixing papaverine and heparin must be avoided to eliminate precipitation.

For FFRren analysis, baseline Pa and Pd measurements are obtained and recorded by the RADI analyzer. RA vasodilatation is performed by an intra-arterial injection of 20 mg of papaverine. Simultaneous phasic and mean aortic and distal RA pressures are monitored and FFRren is calculated as the ratio of Pd/Pa at maximal hyperemic vasodilation. If renal revascularization is performed, a postprocedural Pressurewire TSPG and FFRren is performed (as described previously) and recorded.

Questionnaire and Decision Making

A simple questionnaire was completed in our 89 RAS cases by the treating clinician assessing the influence of this information on immediate procedural decision making comparing the actual procedure performed with the clinician's best-predicted planned procedure. The clinician was first asked the best prediction of the treatment (stent or no stent) before the PressureWire analysis. The clinician was then asked (A) Did the TSPG or FFRren significantly influence procedure decision making? (yes/no). And, if yes, (B) stenting? (yes/no) or no stenting? (yes/no). Twenty-nine of 89 (32.5%) reported, "yes, this information significantly influenced decision making." Nineteen of 89 (21.3 %) reported "stented or added a stent," in cases in which they did not predict a stent would be used. A significant procedural decision-making change was seen most often in patients with a moderate RAS identified on MDCTA or during a previous CADSA in which the RAS was estimated to be 50% to 70%. In these 19 patients, the clinician performed RA PTA/stenting in lesions believed to be significant only after papaverine

provocation and a TSPG was found to be >20 mm Hg. In five cases, a >10 mm Hg TSPG found immediately after PTA/stent occurred and resulted in identification of three missed ostia and two underdeployed stents. Each case was corrected immediately and resulted in postprocedural TSPGs <5 mm Hg. IVUS was not routinely performed in this analysis. In 10 of 89 cases (11.2%), a stent was not deployed when resting and postprovocation TSPGs were <20 mm Hg in cases in which the CADSA or MDCTA had predicted >60% to 70% stenosis.

RESULTS

TSPG/FFRren Analysis

There were no PressureWire or papaverine-related complications. Eighty-nine patients had 4-F catheter and PressureWire TSPG analysis with FFRren and were compared to CADSA. Additionally, 48 of 89 patients (56.4%) were compared to MDCTA. CADSA and MDCTA percent stenosis did not strongly correlate to 4-F catheter TSPG (r^2 = 0.224) but did correlate strongly with PressureWire TSPG (r^2 = 0.610). A FFRren of <0.75 did not strongly correlate with CADSA (r^2 = 0.210), MDCTA (r^2 = 0.191), or 4-F catheter TSPG (r^2 = 0.246), raising the issue that the current FFRmyo concept may be inappropriate in the renal vasculature (FFRren).

To Stent? Or Not to Stent?

The identification and decision to treat moderate-to-intermediate angiographically significant RAS (60%-70% stenosis or ≥50% luminal diameter reduction) is not always straightforward considering the known limitations of CADSA, MDCTA, and TSPG. These intermediate lesions may be functionally significant. No consensus exists as to the minimal TSPG required to treat RAS, and there is a lack of data available to use as a guideline for treatment. Earlier RA PTA/stent trials accepted ≥5 mm Hg transcatheter TSPG to define a suboptimal/failed PTA requiring stenting. A ≥20 mm Hg TSPG has been recently proposed for RAS clinical trials, but this may be an arbitrary number without any physiological basis.[19] Considering the lack of a consensus RAS treatment guideline, we currently use >20 mm Hg TSPG, resting or after injection of 20 mg of papaverine, as an indication to primarily treat RAS and <5 mm Hg PressureWire TSPG post-PTA/stent to define our procedural success and rule out missed lesions, dissections, or stent underdeployment.

More than 30% of our cases experienced major clinical decision changes after papaverine provocation, with approximately 20% stented and 10% not stented in cases in which these treatments were not definitely planned. The PressureWire potentially helped identify those patients who have angiographically moderate but functionally significant

TABLE 1. POTENTIAL BENEFITS OF PRESSURE WIRE ANALYSIS AND FUNCTIONAL RENAL REVASCULARIZATION

- Improved accuracy in identification of RAS
- Identification of physiologically significant RAS
- Functional assessment of intermediate (50%-70%) lesions
- Improved treatment staging of bilateral RAS
- Identification of angiographically significant but physiologically nonsignificant RAS
- Optimizing stent deployment
- Identifying intraprocedural technical problems (dissections, "missed ostias," residual gradients, underdeployed stents, etc.)
- Improved prediction of clinical outcomes with/without stenting
- Objective documentation of indications to treat (PTA/stent)
- Less contrast utilization
- Less fluoroscopic and radiographic exposure
- Identification and treatment of RA ISR lesions
- Decrease RA ISR rates
- Identify the 30%-40% of "poor clinical responders" after PTA/stenting
- Overall improved clinical outcomes

RAS who would not be offered PTA/stenting who "functionally" need it, and therefore should receive functional benefit from PTA/stenting. Conversely, the PressureWire may have the potential to identify those patients who are not likely to clinically benefit from RA PTA/stenting, therefore not exposing them to the 12% to 29% RA ISR rates and the current 30% to 40% of RAS patients not receiving clinical benefit after RA PTA/stenting. Long-term clinical follow-up will be required to answer these questions.

In our analysis, 12 of 89 (13.5%) had RA ISR, and identifying and treating this ISR patient population is problematic. Traditional CADSA has significant limitations in diagnosing RA ISR, but MDCTA allows improved imaging, and curved coronal imaging and flow probing software have allowed more accurate assessment in RA ISR.[16] Treatment for RA ISR is not defined with results of PTA only or restenting reporting approximately 50% restenosis rates.[17,18,30,34-36] We now use 4-quadrant excimer laser atheroablation as our treatment of choice in RA ISR patients and we now use the PressureWire to gauge the number of laser catheter passes required to achieve our goal of a TSPG of <5 mm Hg. This technique has decreased our need for aggressive repeat

high-pressure PTA and the need for repeat stenting (stent sandwich) (Figure 4). We recently reported this technique in 25 RA ISR patients with a 92% procedural success rate and a 10% 6-month >50% restenosis rate as determined by duplex ultrasound.[36]

Optimizing Renal Stent Deployment

RA ISR has been reported in 12% to 29% of cases and is dependent on vessel size, minimal luminal diameters (MLD) or acute procedural gain after stent placement, and optimal stent deployment technique.[12] Lederman et al reported MLD after RA PTA/stent and vessel size correlated with clinical outcomes and reported RA ISR rates of 36%, 15.8%, and 6.5% for vessels <4.5 mm, 4–6 mm, and >6 mm, respectively.[12] Suboptimal stent expansion, missed ostial lesions, and unrecognized distal dissections are all implicated in increased RA restenosis rates and potentially could be identified periprocedurally by TSPG and/or FFRren, allowing for immediate correction and optimized outcomes similar to the reports in PCI by Hanekamp et al and Pijls et al.[23,25] This study has confirmed the work of Colyer et al and identified the PressureWire TSPG to be more accurate than 4-F catheter TSPG, therefore highlighting the known limitation of measuring TSPG with guiding catheters.[19]

The 4-F catheter TSPG method is still advocated as a practice guideline and is used in clinical trials.[19] Although we were unable to identify a strong correlation between FFRren and TSPG, we found the PressureWire TSPG to highly correlate with CADSA and MDCTA and to be a simple and accurate means to document intraprocedure treatment decisions both before and after stenting. The >30% rate of influence on clinical decision making seen in our 89 patients is the first published data accessing intraprocedure decision making in treating RAS. We now use PressureWire analysis for decision making in treating celiac and superior mesenteric artery disease and we are investigating other utilizations in peripheral vascular disease. Similar to RAS, treating visceral arterial disease is limited by diagnostic imaging accuracy, identification of functional stenosis, and high ISR rates.[37]

Limitations

This small single-center study has shown the safety and feasibility of using the PressureWire in accessing RAS but has not provided clinical follow-up or demonstrated clinical efficacy and will require long-term multicenter validation. This study has not unraveled the conundrum between assessing RAS by objective imaging, TSPG, identification of functional RAS, and correlation between RAS, clinical manifestations, and outcomes. This study is, however, a first step in providing insight into optimizing functional renal revascularization. The lack of a correlation between the clinical usefulness of

the FFRmyo <0.75 and an analogous FFRren validation in this report should not be surprising because extrapolating experience from PCI and the coronary bed into the renal artery bed is likely not that simple, further underscoring the differences in coronary artery disease and peripheral vascular disease. This study has confirmed that pressure gradients (TSPG) obtained by PressureWire measurements are more accurate in identifying anatomic RAS than gradients obtained by catheter measurements, MDCTA, or CADSA imaging.

CONCLUSION

The many current limitations in assessing and treating RAS and the proven PCI benefits of FFRmyo are compelling reasons to further pursue PressureWire investigations in peripheral vascular disease and identify the keys to developing a FFRren analogous to FFRmyo. The potential benefits of FFRren in RAS, if analogous to the benefits of FFRmyo in PCI, would have significant clinical implications (Table 1). We now recommend the RADI PressureWire analysis on all RAS cases utilizing a PressureWire TSPG of >20 mm Hg (resting or after papaverine injection) as objective documentation to treat. Our goal is to achieve ≤5 mm Hg PressureWire gradient (resting and postprovocation) after PTA/stenting to define optimal treatment. We now rely heavily on PressureWire TSPG, not catheter gradients or angiography, in our clinical decision making during RAS treatment. It is now time to reproduce the elegant work by Pijls, DeBruyne, Bech, and Kern in PCI and FFRmyo in peripheral arterial disease, and validate an analogous renal model with a goal to provide more optimal functional revascularization in RAS and other peripheral vascular beds, including celiac, mesenteric, and infrainguinal arterial disease. ■

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