Decreased Pulmonary Perfusion in Pulmonary Vein Stenosis After Radiofrequency Ablation

Assessment With Dynamic Magnetic Resonance Perfusion Imaging

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Study objectives: The functional impact of pulmonary vein (PV) stenosis on pulmonary perfusion after radiofrequency ablation (RFA) for atrial fibrillation (AF) has not been systematically evaluated previously. Therefore, we correlated magnetic resonance (MR) pulmonary perfusion imaging with single-photon emission CT (SPECT) perfusion and with the degree of PV stenosis (PVS) apparent on MR angiography (MRA) after RF ablation.

Setting: Joint radiology-cardiology collaborative magnetic resonance unit at the Kerckhoff Heart Center.

Design and patients: This was a cohort study of 110 patients who were routinely examined by MRA after RFA for AF, whereby 51 patients with a PV diameter reduction of >25% or with clinical symptoms (ie, dyspnea and cough) were enrolled into the study. Patients were examined at follow-up by MR perfusion imaging and MRA, and the results were compared to those from patients who underwent SPECT scanning and from a control group of 26 untreated patients. Twelve patients underwent PVS dilatation as well as 22 sequential follow-up examinations.

Methods: Pulmonary perfusion was evaluated using a dynamic contrast-enhanced three-dimensional MR perfusion sequence (1.5 T, 2.5-s temporal resolution, and 0.05 cm spatial resolution), and high-resolution, contrast-enhanced MRA was performed to measure PV diameter. PV dilatation was performed using an angioplasty catheter that was 8 to 10 mm in diameter.

Results: The localization and extent of perfusion defects measured by MRI or SPECT scanning were precisely matched. MR perfusion imaging detected 20 of 21 perfusion defects (sensitivity, 95.2%; specificity, 100%). PVSs and perfusion deficits correlated closely and showed the following threshold: perfusion decreased substantially in PVs <6 mm in diameter (21 of 25 areas; 84.0%) compared to 2 of 180 areas (1.1%) with PVs >6 mm in diameter. After PVS dilatation, perfusion was restored partially after weeks, and complete normalization was seen in 4 of 12 patients (33%).

Conclusions: PVSs caused severe perfusion deficits, which were reliably demonstrated by MR perfusion imaging. Clinical symptoms correlated better with MR perfusion than they did with MRA. The combination with MRA to assess underlying PVS allowed a “one-stop-shopping” MRI procedure to be carried out. The results led to alterations of RFA techniques, and therefore MRA and MR perfusion imaging may be beneficial in patient follow-up and in evaluating new ablation techniques.

Key words: MRI; pulmonary perfusion; pulmonary vein stenosis; radiofrequency catheter ablation

Abbreviations: AF = atrial fibrillation; BW = body weight; CE = contrast-enhanced; FOV = field of view; MPR = multiplanar reconstructed; MR = magnetic resonance; MRA = magnetic resonance angiography; PV = pulmonary vein; PVS = pulmonary vein stenosis; RFA = radiofrequency ablation; SI = signal intensity; SPECT = single-photon emission CT; 3D = three-dimensional

Catheter-guided radiofrequency ablation (RFA) at the orifices of pulmonary veins (PVs) represents a very efficient treatment modality for atrial fibrillation (AF).1 The occurrence of PV stenoses (PVSs) is a well-known complication.2,3 Magnetic resonance angiography (MRA) was reported to be useful for the diagnosis of PVS.4 A first systematic analysis of larger patient groups was performed by transesophageal echocardiography,5 and more recently by multislice CT scanning6 and MRA.7 MRA visualizes the vari-
able PV anatomy in an operator-independent manner\textsuperscript{7,8} and permits the localization of PVSs.

The functional consequences of PVS after RFA on pulmonary perfusion are difficult to assess solely from PV diameter reductions. The amount and extent of the potentially reduced pulmonary perfusion in corresponding pulmonary segments may also depend on collateral blood flow and atypical segmental veins (eg, lingula). An analysis of segmental PV by MRA is difficult because of the inherent variability in the vascular architecture. Pulmonary perfusion has been evaluated in selected patients with suspected PVS after RFA by scintigraphy,\textsuperscript{3} but no systematic analysis of pulmonary perfusion in patients with PVS has been performed to date.

Pulmonary perfusion imaging in MRI has evolved thanks to hardware and software developments. Time-resolved, contrast-enhanced (CE), three-dimensional (3D) perfusion imaging of the entire lung can now distinguish different phases of the contrast medium bolus passage through the lung.\textsuperscript{9} Magnetic resonance (MR) pulmonary perfusion imaging has been applied for assessing pulmonary embolism,\textsuperscript{10,11} and COPD,\textsuperscript{12} for demonstrating perfusion effects of pulmonary malignancies,\textsuperscript{13} but not yet for evaluating PVS. Experience with percutaneous PV dilatation or surgery for the treatment of PVS is limited,\textsuperscript{14–16} and little is known about how pulmonary perfusion recovers after PV dilatation.

The purpose of this study was therefore threefold, as follows: (1) to evaluate feasibility and the value of 3D rapid time-resolved MR pulmonary perfusion imaging in patients with PVS; (2) to assess for the first time systematically the functional consequences of PVS on pulmonary perfusion in patients after RFA by combining MR perfusion imaging, MRA, and single-photon emission CT (SPECT) perfusion; and (3) to monitor perfusion recovery after PV dilatation by follow-up perfusion examinations at various times after intervention.

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Materials and Methods

Control Group

First, MR perfusion imaging was evaluated in a control group of 26 patients (mean ± SD age, 62.3 ± 17.2 years) without any history or suspicion of pulmonary disease or pulmonary perfusion disorder (eg, embolism, pneumonia, malformation, or PVS). Indications for an MR examination in these patients were as follows: an evaluation of left ventricular aneurysm prior to cardiac surgery in 24 patients; and postoperative control after resection of left ventricular aneurysm in 2 patients. The MR protocol in these patients required contrast media administration, but no bolus administration of contrast medium. The bolus of contrast medium was in turn used for pulmonary perfusion imaging.

Study Population

RFA Group: The study population was a subgroup of patients who had undergone RFA for the treatment of paroxysmal AF. These patients had been prospectively enrolled in a protocol including MRA of the PV the day before and after undergoing RFA, and 3 as well as 12 months after undergoing RFA. The study design and results have been published elsewhere.\textsuperscript{7} The technique of RFA used was similar to published protocols\textsuperscript{1,3,5,7} for the treatment of paroxysmal AF. Energies in the range between 15 and 50 W were applied via a cooled tip catheter, and PV isolation or semicircular or focal ablation was performed. MRA proved to be an accurate and reproducible method for the assessment of PVS.\textsuperscript{7} From August 2002 to February 2003, 110 patients in 190 examinations were studied according to the aforementioned protocol.

Patients Examined by MR Pulmonary Perfusion: A subgroup consisting of all patients who had previously undergone MRA showing a PV diameter reduction of ≥ 25% or presenting clinical symptoms (ie, dyspnea and cough) was enrolled into the present study. Figure 1 shows the study protocol. Forty-five patients were enrolled because of PV diameter reduction (main PV diameter reduction, 43 patients; lingular stenoses, 2 patients), and 6 patients were enrolled because of clinical symptoms. Additional MR perfusion examinations were performed at the scheduled follow-ups. Therefore, 51 patients (29 men and 22 women; mean age, 56.1 ± 9.2 years; age range, 37 to 68 years) underwent a combined examination of PV morphology by CE-MRA and an assessment of pulmonary perfusion using dynamic MR perfusion imaging. The results of pulmonary perfusion scintigraphy could be obtained in 39 patients within 24 h of the MR examination (due to limited SPECT scanning availability). Informed consent was obtained from all patients.

PV Dilatation: Twelve patients whose initial perfusion examinations had shown marked perfusion deficits underwent percutaneous PV dilatation with angioplasty balloons that were 8 to 10 mm in diameter due to the discovery of PVS on MRA. These patients also were examined in 22 postinterventional follow-up examinations. As such, a total of 73 combined MR perfusion and MRA examinations were performed from August 2002 to February 2003.

Clinical Symptoms: All patients had been asked about symptoms of pulmonary perfusion disturbances (ie, dyspnea at rest or induced by effort, or cough due to local congestion).

MRA

Sequence: All examinations were performed on a 1.5-T MRI scanner (Magnetom Sonata; Siemens Medical Systems; Erlangen, Germany). A body array coil was placed on the patient’s
chest, with the arms alongside the body. PV angiography used a standard flash 3D CE-MRA sequence (repetition time, 3.2 ms; echo time, 1.4 ms; flip angle, 25°; fat saturation, coronal orientation, 72 partitions; field of view [FOV], 340 mm [512 × 384 pixels]; voxel size, 0.7 × 1.2 × 1.5 mm; and acquisition time, 23 s). The contrast media bolus was targeted for peak enhancement in the left atrium as determined by a bolus timing sequence. The contrast media (0.1 mmol/kg body weight [BW]) was injected at 3 mL/s followed by a 20-mL saline solution flush at 3 mL/s.

Evaluation: The basis of evaluation was the main PV for MRA analysis and the corresponding area for perfusion analysis (for upper PV, upper and middle lobe/lingula; for lower PV, lower lobe). Since one patient had a separate right middle PV, 205 PVs were evaluated. Segmental perfusion defects and segmental PVSs were evaluated separately. Raw images and maximum intensity projections were used for identifying each PV, while the final evaluation and vessel diameter measurements were performed on multiplanar reconstructed (MPR) images in two adapted perpendicular oblique planes. The four main PV diameters were measured near the orifices. PVSs were classified by their residual diameter instead of the degree of stenosis, since the former could be measured more accurately because of the conical shape of the PV and the early vessel branching. Vessel diameters were grouped as follows: diameter reduction or normal, > 11 mm; mild stenosis, 7 to 11 mm; marked stenosis, 4 to 6 mm; severe stenosis, 2 to 3 mm; and occlusion. A diameter of < 4 mm was classified as stenosis for the lingula vein.

All examinations were independently evaluated by two readers. If discordant, the mean value was used for further evaluations.

Perfusion Imaging

Sequence: A time-resolved fast 3D flash gradient-echo sequence was used for the visualization of pulmonary perfusion. The sequence parameters optimized for minimal acquisition time were as follows: TR, 1.6 ms; TE, 0.6 ms; flip angle, 25°; readout bandwidth, 1,500 Hz/pixel; matrix size, 256 × 128 to 192; and FOV, 400 × 200 to 300 mm (the rectangular FOV was adapted to the patient’s thoracic diameter). A 3D slab (thickness, 200 mm; transverse partitions of 10 mm each, 20; voxel size, 2.9 × 1.6 × 10 mm [0.05 to 0.04 cm3]) covered the entire lung from the apex to the diaphragm. The typical acquisition time was 2.5 s (range, 2.3 to 3 s [depending on the number of phase-encoding steps]). Eighteen measurements of 40 to 50 s (360 images) covered the first pass of the contrast media bolus through the pulmonary vasculature in all patients, and the second pass in most of the patients.

No ECG or respiratory gating was applied. The patients were instructed to hold their breath in end-inspiration as long as possible and to resume free breathing afterward. As such, the constant position of the diaphragm for at least 24 to 30 s sufficed for the first-pass analysis in all examinations.

The sequence was started simultaneously with a contrast media bolus of 0.15 mmol/kg BW, consisting of 0.5 mmol/mL gadopentate dimeglumine (Magnevist; Schering; Berlin, Germany) at 5 mL/s with a power injector (Spectris Medrad; Pittsburgh, PA) followed by a 20-mL saline solution flush at 5 mL/s.

Evaluation: Perfusion images were arranged in chronologic order for visualizing the bolus passage through each transverse slice, and in spatial order for visualizing the entire lung during each single phase. MPR images from a coronal view served to assess subtle unilateral perfusion deficits of larger areas (e.g., slight

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**Figure 1. Scheme for the study on pulmonary perfusion in patients with PVS.**

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Validation of MR Perfusion

The criterion for diagnosing reduced perfusion was the spatial distribution of signal intensity (SI) at peak parenchymal enhancement, and not the contrast media dynamic. The calculation of relative enhancement and its proportion in normal/decreased areas was also performed.

Changes of pulmonary perfusion in MR after dilatation were quantified by calculating the ratio of relative enhancement in areas with pathologic perfusion compared to the enhancement of corresponding normal areas of the contralateral lung, in which a ratio of 1 signifies similar enhancement in both lungs. Thus, normal perfusion was assumed for a left-to-right enhancement ratio of between 0.95 and 1.05.

Nuclear Medicine

Thirty-nine SPECT perfusion scans were performed as a reference for pulmonary perfusion within 24 h of the MRI examination using a 180° dual-head camera (Ecam; Siemens Medical Systems). 3D SPECT perfusion scan data were transformed into 64 transverse slices per examination. Two-dimensional planar lung scans with eight standard projections were performed in two patients who were unable to keep their arms above their head. A total of 148 MBq Tc-macromaggregated albumin was used as the radiopharmaceutical. Sharply delineated areas of markedly decreased perfusion were classified as perfusion deficits, while patchy multilocular areas of slightly decreased perfusion were classified as COPD.

Statistical Analysis

Values are given as the mean ± SD (range [if indicated]). Frequencies were compared using the Fisher exact test, while the two-tailed Student t test was applied to test differences between mean values.

Results

All 51 patients enrolled for PV diameter reduction of > 25% from 110 patients examined after RFA completed the combined MR perfusion/MRA protocol as scheduled. Twelve of these patients developed a severe PVS or clinical symptoms, and therefore underwent PV dilatation and were controlled in 22 follow-up examinations.

Validation of MR Perfusion

Control Group: All 26 examinations in the control group showed normal homogeneous pulmonary perfusion without lobar, segmental, or subsegmental perfusion defects or right/left differences, thus no false-positive findings occurred.

MR Perfusion Compared to SPECT Perfusion: Table 1 shows the sensitivity, specificity, positive predictive value, and negative predictive value for MR perfusion imaging compared to those for SPECT perfusion. The frequency of perfusion defects did not differ significantly (p > 0.1) between the study group and the SPECT perfusion subgroup. Of 39 SPECT perfusion lung scans obtained within 24 h of the MR perfusion examination, 21 examinations (53.8%) showed reduced pulmonary perfusion compared to 20 examinations with MR perfusion imaging. Twenty-two of 24 scintigraphic perfusion defects were seen in MR perfusion imaging. Two SPECT perfusion disturbances had been initially missed in the MR perfusion imaging and were acknowledged retrospectively.

All MR perfusion defects corresponded to analogous perfusion defects at the same localization in the lung scans, but perfusion disturbances were more pronounced in lung scans than they were in the MRI. No patchy perfusion disorders consistent with COPD were found in either SPECT scans or MRI.

Figure 2 illustrates findings from a 56-year-old woman. Areas of MRI and scintigraphic perfusion defects matched exactly.

PV Diameter and Pulmonary Perfusion

MRA: Forty-three of 51 examinations (84.3%) and 58 of 205 main PVs (28.3%) showed at least mild stenosis. The mean diameters of 125 main PVs that had not been treated was 14.6 ± 2.4 mm, and the mean diameter of 80 treated PVs was 7.9 ± 2.1 mm. Additionally, 8 of 51 lingula veins (15.7%) showed a diameter of ≤ 4 mm, while the mean lingula vein diameter in patients not treated by ablation of the left upper PV was 6.7 mm. Two lingula PVs were detected retrospectively when MR perfusion revealed lingula perfusion defects.

Table 1—Sensitivity and Specificity of MR Perfusion Compared to SPECT Perfusion

<table>
<thead>
<tr>
<th>Examination (n = 39)</th>
<th>Normal Perfusion</th>
<th>Pathologic Perfusion</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>18</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Pathologic perfusion</td>
<td>0</td>
<td>20†</td>
<td>20</td>
</tr>
<tr>
<td>Normal perfusion</td>
<td>18</td>
<td>21</td>
<td>39</td>
</tr>
<tr>
<td>Area (n = 156)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal perfusion</td>
<td>132</td>
<td>2</td>
<td>134</td>
</tr>
<tr>
<td>Pathologic perfusion</td>
<td>0</td>
<td>22†</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td>132</td>
<td>24</td>
<td>156</td>
</tr>
</tbody>
</table>

*For MR perfusion imaging: prevalence, 53.8%; sensitivity, 95.2%; specificity, 100%; positive predictive value, 100%; negative predictive value, 94.7%.
†For MR perfusion imaging: prevalence, 15.4%; sensitivity, 91.7%; specificity, 100%; positive predictive value, 100%; negative predictive value, 98.5%.

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Figure 3, left, demonstrates the relationship between pulmonary perfusion and PVS. With a threshold value of 6 mm, 2 perfusion defects were seen in 180 areas (1.1%) drained by the PV with a diameter of >6 mm, while 21 perfusion defects were seen in 25 areas (84.0%) drained by the PV with a diameter of ≲6 mm (p < 0.0001).

MR Perfusion: Perfusion images of all patients reached diagnostic quality, and phases of selective pulmonary artery, parenchymal, and PV contrast could be distinguished. The mean examination time, including patient positioning, scout views, bolus timing sequence, MR perfusion, and MRA, was 13 min (range, 9 to 18 min). Perfusion imaging required 2 to 3 min. The mean parenchymal pulmonary SI in normal lower lobe areas increased by 6.7 ± 2.3-fold (range, 2.6 to 16-fold) compared to precontrast SI. A ventrodorsal gradient caused lower relative enhancement of the middle lobe and lingula segment (mean, 2.9 ± 1.1-fold; range, 2.1 to 7-fold) compared to dorsal parts of the lower lobe.

Twenty-one of 51 patients (41.1%) showed perfusion deficits in 23 of 205 examined areas (11.2%). All perfusion defects corresponded to segmental or lobar margins, with no subsegmental perfusion defects. Two patients showed an isolated perfusion defect of the lingula segment. Relative enhancement in areas with perfusion impairments (mean, 3.4 ± 1.9-fold; range, 1.2 to 6-fold) was significantly lower compared to the contralateral normal areas (p < 0.001). The mean quotient of relative enhancement in areas of decreased perfusion vs contralateral normal areas was 0.51 ± 0.39 (range, 0.14 to 0.96).

Clinical Symptoms: Forty-five patients who were enrolled into the study showed no symptoms, while 6 patients complained of dyspnea or cough. Two of these six patients showed a decreased perfusion of an entire lung, one patient showed bilobar perfusion deficits, and three patients showed lobar perfusion deficits. In 45 patients who did not complain of dyspnea or cough, no perfusion defects of an entire, whole lung (i.e., no disease so severe that it affected...
the left or right lung entirely) were seen, and no perfusion defects affecting two lobes simultaneously were detected.

Follow-up Examinations After Dilatation

Twelve patients underwent balloon dilatation of PVSs. All these patients showed perfusion defects on MR perfusion imaging and severe stenosis on MRA. Six of these patients complained of effort-induced dyspnea. Two patients had to be dilated twice after the recurrence of perfusion deficits and PVSs. The intervention was initially successful in all but one patient, whereby the postinterventional diameter was > 7 mm in 7 of 12 PVSs and > 5 mm in 4 PVSs.

Typical MRA, MR perfusion, and SPECT images before and directly after PV dilatation (Fig 4) revealed a partial recovery of pulmonary perfusion. Figure 5 demonstrates changes in pulmonary perfusion after PV dilatation for 12 patients before dilatation, and during 22 follow-up examinations after dilatation. Pulmonary perfusion partially recovered over weeks, and complete normalization was seen in 2 of 12 patients (17%).

The relationship between PV diameter and pulmonary perfusion after dilatation is presented in Figure 3, right, for 88 controlled PVSs (ie, 4 PVSs evaluated in 22 examinations). A diameter of ≤ 3 mm was seen in five examinations in three patients, indicating recurrences of stenosis. Unlike results before dilatation (Fig 3, left), whereby PV diameters of ≥ 6 mm were sufficient for normal pulmonary perfusion, and reduced perfusion in areas of preexisting severe stenosis did not fully normalize despite postinterventional PV diameters of ≥ 6 mm.

Clinical Symptoms:

A discernible minor perfusion disturbance persisted in all six patients complaining of effort-induced dyspnea before dilatation. However, the left-to-right enhancement ratio improved to 0.8, 0.95, and 1.02 in three patients with relieved symptoms, increased to 0.6 and 0.58 in two patients with clinical improvement, and increased over weeks to 0.4 in a patient still complaining of dyspnea.

Discussion

MR Perfusion Imaging

MR pulmonary perfusion imaging proved to be reliable for the assessment of pulmonary perfusion,
whereby areas of decreased perfusion were precisely matched in both MR perfusion imaging and SPECT perfusion imaging. MR perfusion imaging reached 95.2% sensitivity. Anatomic landmarks in MRI (pulmonary vessels and lobar fissures) and better spatial resolution compared to SPECT scanning eased the diagnosis. A higher contrast between normal and decreased perfusion compared to MRI is inherent to SPECT imaging since it visualizes purely pulmonary perfusion without any surrounding structures. Both MRI and lung scans were able to exclude subsegmental perfusion disorders that might have indicated other pulmonary diseases (e.g., pulmonary embolism or COPD). No ventilation scans were performed.
since the aim of this study was the evaluation of MR perfusion imaging, and increasing the specificity of scintigraphy was not required.

**PVS**

The frequency of PVS, a known complication of RFA treatment for AF, ranged from 18 to 25% in two systematic studies using multislice CT scanning and MRA. Reliability, investigator independence, and postprocessing evaluation represent advantages of these techniques compared to transesophageal echocardiography.

This study is the first to systematically evaluate the functional impact of PVS on pulmonary perfusion. A pronounced decrease of pulmonary perfusion in areas with PVS (i.e., a nonlinear relationship between PVS and pulmonary perfusion) [cutoff value, approximately 6 mm] was seen. All perfusion disturbances could be traced to underlying PVSs, while all control group examinations showed normal perfusion.

**Pathophysiology**

Few studies, however, have assessed the pathophysiologic effects of chronic PVS and pulmonary perfusion. Acute PV occlusion in dogs arrests pulmonary arterial flow in 4 s, and an occlusion-induced increase in PV pressure to pulmonary arterial levels halts pulmonary flow. Reports in selected patients with chronic PVS showed an impaired pulmonary perfusion on scintigraphy. Persistent perfusion deficits after PV dilatation that recovered slowly over weeks, as seen in this study, indicate structural changes of the pulmonary vasculature.

**Clinical Consequences**

Regarding clinical consequences, knowledge has been added to the understanding of RFA, since segmental stenoses were detected as far as 1 cm distally from the PV ostium. The accuracy of the localization of the ostium during RFA intervention...
was therefore overestimated beforehand. The detection of side-branch occlusion of the main PV is difficult in MRA because of the variable PV anatomy. Therefore, segmental PVS (particularly the lingula PV) was rarely diagnosed initially by MRA but was instead diagnosed from the presence of segmental perfusion defects. Clinical symptoms correlated better with the extent of perfusion deficits than they did with PVS. MR pulmonary perfusion deficits with severe PVS contributed to an indication for PVS dilatation. MR perfusion imaging therefore has initiated a reassessment of RFA and PVS dilatation techniques.

Methodology

Although relative enhancement in pathologic and normal perfused pulmonary areas differed statistically with high significance, a diagnosis based on enhancement ratio alone was not reliable because of the overlapping mean values. Areas of previous perfusion deficits remained discernible after PV dilatation due to the subtly decreased and delayed perfusion that could be better detected by visual analyses. The left/right ratio of relative enhancement, however, seemed to describe smaller perfusion disturbances more reliably.

The contrast agent dosage of 0.15 mmol/kg BW for perfusion imaging was chosen after preceding experiments had revealed moderate enhancement with lower dosages, while doses of > 0.15 mmol/kg showed no advantageous parenchymal enhancement. The cumulative dosage of 0.25 mmol/kg BW applied in this study lies within in the accepted range for safe clinical use.24–26

The patient group chosen here represents a selection of all patients treated by RFA for paroxysmal AF. Examinations were performed in patients with diameter reduction known from previous MRA or in patients showing clinical symptoms (e.g., dyspnea or cough). Due to this selection bias toward more severe PV afflictions, no assumption can be made about the rate of PVS after RFA for AF.

Conclusion and Implications

The functional consequences of PVS have been underestimated until now. A combined “one-stop shopping” MRA and MR perfusion examination allowed the visualization of both PVS and subsequent perfusion defects. PVS below a cutoff value of approximately 6 mm invariably resulted in marked and extended perfusion deficits, which led to a reevaluation of the RFA and PV dilatation techniques.

While the mechanism underlying the slow perfusion recovery after PVS dilatation is not understood to date, a gradual reversal of chronic adaptation processes can be postulated. MR perfusion imaging appears to be a valuable addition to the follow-up of patients after RFA and PV dilatation, and may help to evaluate future ablation techniques.

References