Accurate knowledge of the anatomy of the pulmonary veins is important in clinical electrophysiology. In order to evaluate the usefulness of magnetic resonance angiography for this purpose, we studied 17 unselected patients. All the pulmonary veins were visualized in each individual. The diameters of the ostia ranged between 9 mm and 22 mm. The cross-section of the ostium was elliptical in 35% of cases. In 14 patients (82%), the 4 veins each had independent drainage. In 2 patients (12%), there was an additional intermediate right vein and, in 1 patient (6%), both left veins had a common ostium. In 74% of patients, the right pulmonary veins had a short common trunk with early branching. This pattern was seen in only 10% of left veins. Magnetic resonance angiography using a contrast medium is an excellent technique for studying the anatomy of the pulmonary veins and for identifying variants. The resulting information is potentially useful for electrophysiologists.

Key words: Magnetic resonance imaging. Pulmonary veins. Catheter ablation. Atrial fibrillation.

INTRODUCTION

Radiofrequency ablation of ectopic foci located at the junction of the pulmonary veins (PV) in patients with paroxysmal atrial fibrillation has raised interest in imaging techniques capable of offering adequate information on the anatomy of these vessels. The purpose of this study was to determine the usefulness of magnetic resonance angiography (MRI angiography) for routine anatomic study of the PVs.

PATIENTS AND METHODS

The study included 17 consecutive patients who were undergoing cardiac magnetic resonance imaging (cardiac MRI) at our hospital and required the administration of paramagnetic contrast material. Three-dimensional MRI angiography sequences (Philips Intera 1.5T, Best, Netherlands) were taken of all patients during the administration of gadoteridol 0.2 mmol/kg (ProHance, Bracco International BV, Amsterdam, Netherlands) at an infusion speed of 3 mL/s. A detailed analysis was performed of the projected images (Figure 1A), solid three-dimensional...
images (Figure 1B), tomographic images (Figure 1C and 1D), and virtual endoscopy images (Figure 1E), using dedicated software (Easy Vision, Philips Medical Systems, Best, Netherlands and MASS Bonus V 5.0 Medis, Leiden, Netherlands). Because the junction orifice of the pulmonary veins can have an irregular shape, the ostium measurement was systematized by using 2 orthogonal diameters (Figures 1C and 1D) as well as the cross-sectional area, and the mean value and standard deviation were calculated for each main vein. Student’s t test was used to compare the means between numerical variables; significance was set at a P value <.05.

RESULTS

High-quality images allowing interpretive reading were obtained for all patients. Table contains the characteristics of the group studied and the measures obtained.
The diameter of the ostium was between 9 and 22 mm. Although the mean value of the diameters of each ostium in any axis was similar in all the vessels studied, the calculated areas were greater in right than in left PVs, with significant differences between the area of the left inferior PV (6.2±1.9 cm²) and that of the right superior (8.0±2.4 cm²; P=0.02) or right inferior PV (7.6±1.9 cm²; P=0.04), respectively.

In addition, 35% of the ostia had an elliptical shape, defined as a difference ≥3 mm between the 2 orthogonal diameters. This was more evident in the inferior PVs (72% of cases with elliptical ostium) than the superior PVs; the left inferior PV was most frequently found to have an elliptical ostium (61% of all patients).

With regard to the number of ostia, 4 were visualized in 14 patients (82%), 5 in 2 patients (12%), with the supernumerary ostium corresponding to an independent junction of the middle right PV (Figure 2), and 3 in 1 patient (6%) in whom the 2 left PVs had a common junction (Figure 3). These last 3 patients correspond to the preablation cases.

In the case of PV branching, 10 patients (59%) were found to have convergence of the branches of the right PV very near the ostium which resulted in a short common trunk, and 5 patients (29%) had no common trunk, the ostium being formed by direct confluence of the lobar veins (right superior PV, 3 cases; left superior PV, 2 cases; right inferior PV, 1 case). Considered as a whole, the right PVs branched earlier than the left PVs (74% vs 10%).

**DISCUSSION**

The study results show that MRI angiography is an extremely useful technique for routine anatomic study of the PVs, as reported by other authors.\textsuperscript{2,3} Although a complete description of the anatomical characteristics of the veins can be done in all patients using 2D images, 3D solid reconstruction is extremely useful, as it provides a spatial view, whereas 3D virtual endoscopy offers highly illustrative images of the intracardiac arrangement of the PV ostia. This information is useful for the elec-
trophiologist and facilitates the planning and performance of PV catheterization. Because the technique is noninvasive and does not emit ionizing radiation, unlimited follow-up studies can be performed to rule out possible complications secondary to ablation.

The morphological findings observed in our series are consistent with those described in the classic anatomical treatises\(^a\): the superior PVs tend to present larger cross-sectional areas than the inferior veins, just as occurs with the right PVs versus the left PVs, all this in accordance with the size of the pulmonary lobes. Measurement of the ostial diameter on surfaces orthogonal to the longitudinal axis of the vessel made it possible to determine the ostial morphology, which was elliptical in one third of the PVs studied. This justifies the recommendation to use 3D postprocessing techniques.\(^b\) Postablation follow-up to rule out stenosis in the ablated veins should always be done by comparing with the baseline images obtained prior to ablation.

In our series, the 3 patients with PV junction variants corresponded to preablation cases. Because only few cases were studied, it is risky to relate these anomalies to the presentation of paroxysmal atrial fibrillation. Furthermore, although there are data in the literature that suggest a higher prevalence of morphological variants among patients with this arrhythmia,\(^c\)\(^d\)\(^e\)\(^f\) a clear relationship between the 2 phenomena has not been established.

A limitation of the present study is that it was not done in healthy volunteers, but instead with a heterogeneous sample of patients with heart disease, which prevented the measurements obtained in the PV ostium from being considered normal reference values.

**CONCLUSIONS**

Knowledge of the anatomical positions and morphology of the PVs gained by magnetic resonance angiography is highly useful for the electrophysiologist, as it facilitates catheter positioning during pulmonary vein ablation. The availability of accurate information on the morphology of each PV is an advantage for follow-up studies, which can be unlimited due to the non-invasive nature and lack of radiation of cardiac magnetic resonance imaging.

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