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Original Research

Evaluation of Pulmonary Vein Variations Using Multidetector Computed Tomography

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ABSTRACT
Objective: In this study, we aimed to identify variations in pulmonary veins (PVs) that are important for preparation before a radiofrequency ablation (RFA) using 64 multidetector computed tomography (MDCT) and to classify their incidence and drainage types.
Methods: In total, 503 patients, including 312 males and 191 females who were examined by abdominal computed tomography angiography for various reasons between January 2011 and December 2016 were included in this study. A 64-section CT device was used for scanning. Two-dimensional multiplanar reformats were created from axial images, and 3-dimensional images were created using maximum intensity projection and volume rendering methods. PV anatomic variations were identified.
Results: A pulmonary venous drainage pattern with the classical pattern, i.e., four ostia with two ostia on the right and two on the left, was observed in 44.8% of the patients. The remaining patients had varying anatomies on the right or on the left. In addition, 3.4% had right top PV, 72.4% had the classical type with two ostia on the right, whereas 27.6% had the varying type with one ostium or more than two ostia on the right. In addition, 61.5% had the classical pattern with two atrial ostia on the left, whereas 38.5% had the varying drainage patterns with one atrial ostium or three atrial ostia on the left. Our study is important in terms of being the largest series to date with 503 patients. The type that involves three separate atrial ostia on the left classified as L3 (Left) is not included in Marom's classification.
Conclusion: MDCT accurately identifies pulmonary venous anatomy in detail, which is important in RFA preparation.
Keywords: Pulmonary vein, variation, Multidetector Computed Tomography

INTRODUCTION

Like all the veins in our body, the pulmonary vein (PV) shows a different pattern in each individual, called normal variation. Moreover, the PV is an important source of ectopic atrial electrical activity and frequently initiates paroxysmal atrial fibrillation (AF) (1, 2).

Increasingly, selective radiofrequency ablation (RFA) of these arrhythmogenic foci is performed to treat patients with refractory AF. The effectiveness of the RFA procedure relies on mapping the location and complete disconnection of the arrhythmogenic foci on the atrial tissue. Therefore, detailed knowledge of pulmonary venous anatomy and relationships between the PVs and the left atrium is highly necessary for mapping and ablation treatment (3).

Increasing the success of RFA and treating ectopic foci is possible by knowing the common variations in the pulmonary anatomy (4, 5). Therefore, cross-sectional imaging modalities are necessary for mapping pulmonary anatomy and recognizing variant veins before RFA.

Multidetector computed tomography (MDCT) can help visualize the anatomy of the left atrium as well as the number, localization, and diameters of PVs (6-8). Moreover, examinations during planning are used as reference images for detecting complications after RFA treatment. In diagnosing and identifying pulmonary venous anomaly coexisting with isolated and cardiac pathologies, pulmonary vein CT angiography (PVCTA) was reported to have results similar to cardiac catheterization (9, 10).

In our study, we aimed to identify the variations in PVs that are important in RFA preparation and to classify their incidence and drainage patterns using 64-MDCT.

METHODS

In this study, 503 patients who underwent cardiac and thoracic angiography between 2011 and 2016 were retrospectively evaluated. The approval of the ethics committee was obtained from Gaziantep university ethics committee (27.03.2017/43).

Thoracic MDCT examinations were performed to evaluate suspected pulmonary embolism, coronary artery disease, or bypass grafts. Patients who underwent a lung operation and those not suitable for anatomical evaluation due to atelectasis, radiation fibrosis, or hilar mass were excluded from the study. Because of its being a retrospective study we didn't take written patient informed consents

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Table 1. Distribution according to the number of orifices and types on the right

	1		2			3		4		5		
O.S.	**R1**	**R2A**	**R2B**	**R2C**	**R3A**	**R3B**	**R3C**	**R4A**	**R4B**	**R5A**	**R5B**	**Total**
N	7	159	181	24	86	14	1	8	16	5	2	503
%	1.4	31.6	36	4.8	17.1	2.8	0.2	1.6	3.2	1	0.4	100
N	7		364			101		24		7		
%	1.4		72.3			20.1		4.8		1.4		

O.S.: number of orifices; T: type; N: number of cases

Images were obtained using a 64-section (General Electric, Milwaukee ABD) CT device. Bolus administration of 120 mL nonionic contrast agent at 4 mL/s was followed by a bolus administration of 40 mL physiological serum at 4 mL/s through the right or left antecubital vein via an automatic injector (Covidien, ABD), wherein the contrast agent contained 300 mgI/mL iodine. In scanning, 40-mm (64×0,625) collimation, 0.35-s rotation time (s), 1-pitch value, 100-120 kilovolt (kV), 150-600 miliamper (mA), 0.625-mm detector width, and 0.625-mm reconstruction interval were used. Three-dimensional (3D) images were created at the workstation (Vitrea) from all axial images, which were analyzed for anatomic variations by two radiologists and subsequently reported after reaching a mutual decision.

Statistical Analysis

Data were loaded on the SPSS (Statistical Package for Social Sciences) software and evaluated using chi-square method in this software. Some types were grouped to enable statistical evaluation. A $p<0.05$ was considered statistically significant.

RESULTS

Patients were aged 1-91 years (mean, 50.7±19.6 years). The study included 191 women (38%; mean age, 50.3±19.4 years) and 312 men (62%; mean age, 50.9±19.8 years). Left atrium and PVs were imaged clearly using 64-section MDCT in all patients. There was no statistically significant difference among them in terms of gender.

In identifying and classifying pulmonary venous anatomy, we used the classification of Marom et al. (1), which relies on both the number of venous ostia and drainage patterns.

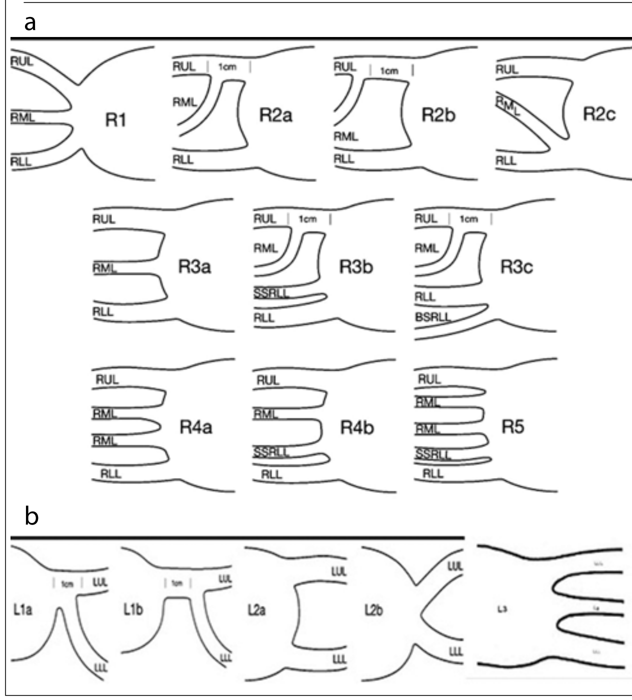
In Marom et al. (1) classification, the first letter (L: Left, R: Right) indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation.

We identified two different types of PV variations that are not included in Marom et al. (1) classification. Therefore, we called these L3 for five patients on the left and R5B for two patients on the right and created two new classes that include these types (Figure 1 a, b).

Right Pulmonary Venous Drainage Patterns

Among 503 patients, 364 (72.3%) had two atrial ostia on the right (Table 1), 181 patients (36%) had R2B, and 159 patients (31.6%) had R2A with high incidence rates. Patients with two orifices on the right also had two orifices on the left at a high incidence rate (44.8%, Table 2, Figure 1). Only seven patients (1.4%) had one ostium (Table 1, Figure 2). The incidence rate of three or more ostia was 26.3% (Figures 3, 4). There was no significant difference in the evaluation of the number of ostia in terms of gender distribution (Table 3).

Figure 1. a, b. Right Pulmonary Vein Types [Marom et al. (1)] (RUL: right upper lobe; RLL: right lower lobe; RML: right middle lobe; SSRLL: right lower lobe superior segment, BSRLL: right lower lobe basal segment) (a); Left Pulmonary Vein Types [(Marom et al. (1)] (LUL: left upper lobe; LLL: left lower lobe, Lg: lingual) (b)



In the present study, 17 patients (3.4%) with right PV (RTPV) drainage patterns that branch from the top of the right PV as an accessory was imaged (Figure 5). RTPV coexisted with six (35.2%) R2B, five (29.4%) R3A, three (17.7%) R2A, one (5.9%) R2C, one (5.9%) R3B, and one (5.9%) R4B types. The incidence of drainage patterns on the left in patients with RTPV was as follows: L1B in eight patients (47%), L2B in five patients (29.4%), L2A in three patients (17.7%), and L1A in one patient (5.9%).

Table 2. Number of left and right orifices together

O.S.		Left 1	Left 2	Left 3	Total
Right	1	4(0.8%)	3(0.6%)	0(0%)	7(1.4%)
	2	136(27%)	225(44.8%)	3(0.6%)	364(72.4%)
	3	36(7.1%)	64(12.7%)	1(0.2%)	101(20%)
	4	10(2%)	13(2.6%)	1(0.2%)	24(4.8%)
	5	3(0.6%)	4(0.8%)	0(0%)	7(1.4%)
	Total	189(37.5%)	309(61.5%)	5(1%)	503(100%)

O.S.: number of orifices

Table 3. Gender distribution according to the number of orifices on the right

O.S.	N	Female	(%)	Male	(%)
1	7	3	(42.8%)	4	(57.2%)
2	364	132	(36.2%)	232	(63.8%)
3	101	42	(41.6%)	59	(58.4%)
4	24	10	(42.5%)	14	(57.8%)
5	7	4	(57.2%)	3	(42.8%)
Total	503	191	(37.9)	312	(62.1%)

O.S.: number of orifices

Table 4. Distribution according to the number of orifices and types on the left

O.S.	1		2		3	
T	L1A	L1B	L2A	L2B	L3	Total
N	60	129	166	143	5	503
%	12	25.6	33	28.4	1	100
N	189		309		5	503
%	37.6		61.4		1	100

O.S.: number of orifices; T: type; N: number of cases

Table 5. Gender distribution according to the number of orifices on the left

O.S.	N	Female	(%)	Male	(%)
1	189	76	(40.2%)	113	(59.8%)
2	309	113	(36.5%)	196	(63.5%)
3	5	2	(40%)	3	(60%)
Total	503	191	(34.1%)	312	(64.9%)

O.S.: number of orifices

In our study, the addition to Marom et al. (1) classification, i.e., R5B was seen in two patients (0.4%). Five different ostia on the right drained the right upper lobe, middle lobe, right lower lobe, lower lobe superior segment, and lower lobe basal segment. Unlike the variation referred to as R5 in Marom et al. (1) classification, it contains one middle lobe vein instead of two middle lobe veins, and the other vein drains the lower lobe basal segment (Figures 6, 7). Two R5Bs that we added to the classification were accompanied by L2A in one and L2B in the other on the left (Table 3, Figure 8).

Figure 2. R2A/L2A. The first letter indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation (L: Left, R: Right)

Figure 3. R1/L2B. The first letter indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation (L: Left, R: Right)

Left Pulmonary Venous Drainage Patterns

Among the 503 patients, classically, 309 (61.4%) had two atrial ostia that drained the upper and lower lobe veins (Table 4). There was no statistically significant difference in gender distribution. Similarly, there was no statistically significant difference in the distribution among genders when grouped according to the number of orifices and type (p>0.05; Table 5). Patients with two orifices on the right generally (44.8%) had two orifices on the left (Figure 9). A high number of ostia was less prevalent on the left compared to the right (Table 2).

Figure 4. R3B/L2B. The first letter indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation (L: Left, R: Right)

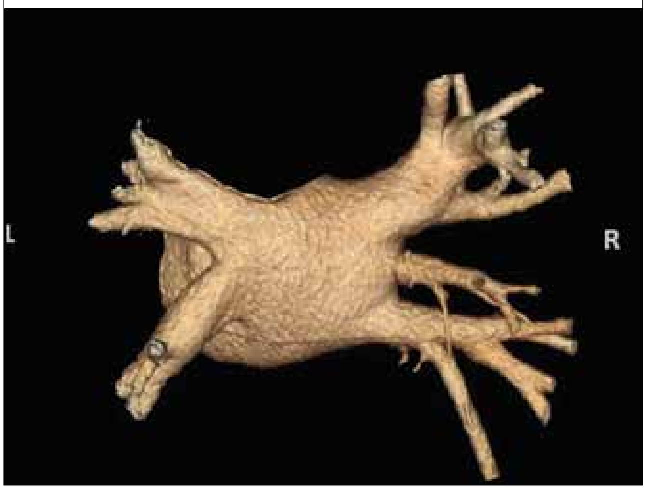


Figure 5. R4B/L1B (OBLIQUE). The first letter indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation (L: Left, R: Right).

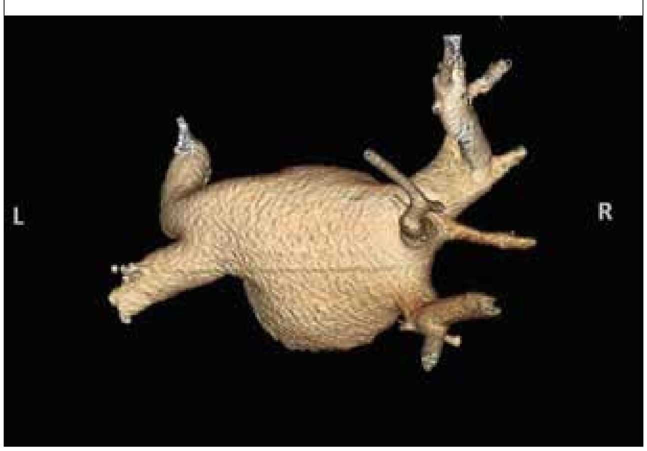


Figure 6. *RTPV
*top of the right pulmonary vein

Figure 7. R5A/L2B. The first letter indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation (L: Left, R: Right)

Figure 8. R5B/L2A. The first letter indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation (L: Left, R: Right)

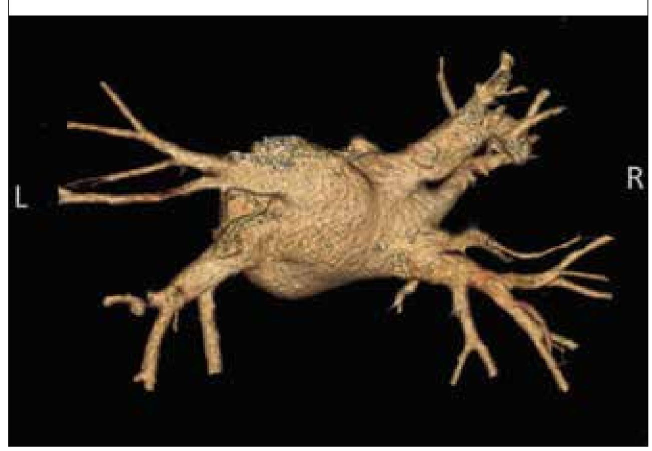


Figure 9. R2B/L1B. The first letter indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation (L: Left, R: Right)

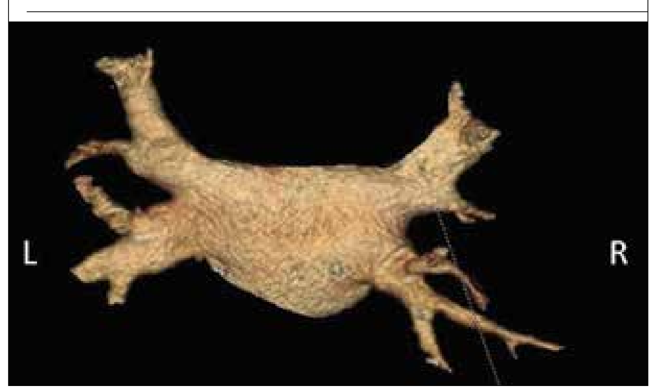


Figure 10. R4A/L1B. The first letter (L: Left, R: Right) indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation

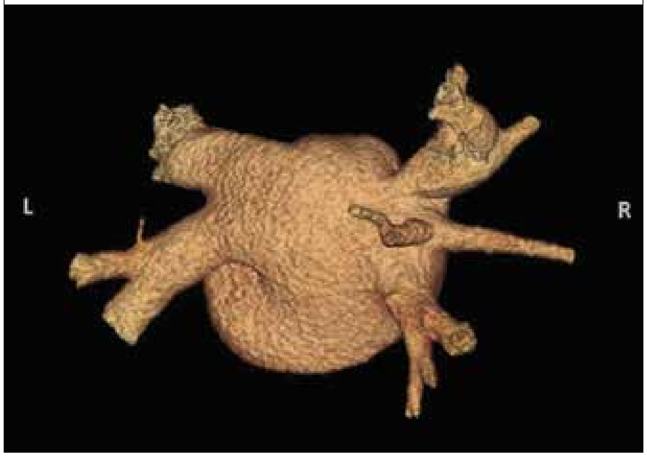


Figure 11. R2B/L3. The first letter indicates the side of the drainage, the following number (1-6) indicates the number of ostia, and the last letter (A, B, and C) defines the variation (L: Left, R: Right)

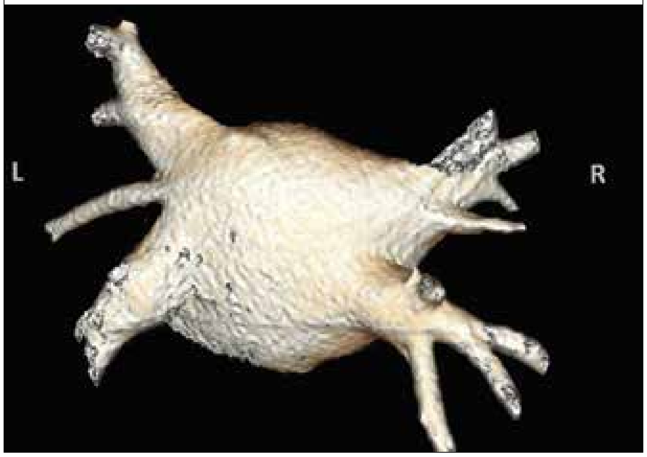


Table 6. Coexistence of right and left pulmonary vein types

	L1A	L1B	L2A	L2B	L3	Total
R1	0 (%)	4 (0.8%)	0 (%)	3 (0.6%)	0 (%)	7 (1.4%)
R2A	21 (4.2%)	39 (7.8%)	51 (10.1%)	48 (9.5%)	0 (0%)	159 (31.6%)
R2B	15 (3%)	47 (9.3%)	64 (12.7%)	52 (10.3%)	3 (0.6%)	181 (35.9%)
R2C	4 (0.8%)	10 (2%)	6 (1.2%)	4 (0.8%)	0 (0%)	24 (4.8%)
R3A	15 (3%)	15 (3%)	30 (6%)	25 (5%)	1 (0.2%)	86 (17.1%)
R3B	2 (0.4%)	4 (0.8%)	3 (0.6%)	5 (1%)	0 (0%)	14 (2.8%)
R3C	0 (0%)	0 (0%)	1 (0.2%)	0 (0%)	0 (0%)	1 (0.2%)
R4A	0 (0.2%)	5 (1%)	1 (0.2%)	2 (0.4%)	0 (0%)	8 (1.6%)
R4B	0 (0%)	5 (1%)	7 (1.4%)	3 (0.6%)	1 (0.2%)	16 (3.2%)
R5A	3 (0.6%)	0 (0%)	2 (0.4%)	0 (0%)	0 (0%)	5 (1%)
R5B	0 (0%)	0 (0%)	1 (0.2%)	1 (0.2%)	0 (0%)	2 (0.4%)
Total	60 (12%)	129 (26%)	166 (33%)	143 (28%)	5 (1%)	503 (100%)

The L1B type with a single orifice constituted the majority of the cases. In L1B, a lingular vein drained into the proximal inferior PV, and these two combined to form a wide common truncus to the superior PV and opened into the left atrium (Figure 10). On the right, R2B was most frequently concurrent with L1B.

In the L3 type on the left seen in five (1%) patients, three ostia were formed by upper, lower, and lingual veins and these three ostia were separated by the left atrial wall (Figure 11). Five patients with L3 type were males. However, a statistical comparison in terms of gender distribution could not be performed because the number of cases was low. The L3 type was accompanied by R2B on the right in three patients, R3A in one patient, and R4B in one patient (Table 6).

DISCUSSION

The incidence of AF in the general population is 1%-2%, wherein the patients are characterized by an increased risk of stroke, thromboembolic complications, cardiac insufficiency, and mortality. (11)Aging is an important risk factor for AF. The cause of AF is the independently formed ectopic electrical foci in the atrium, and these are generally seen around the orifices of the PVs. Other foci localizations comprise the superior vena cava, crista terminalis, sinus coronaries, and interatrial septum. In literature, studies have reported that 94% of these foci are around the PVs (12). However, no connection was identified between variations and diameters of these PVs and AF (1, 13). In RF treatment, the aim was to electrically insulate target PVs by creating a linear scar tissue. In AF recurrences, after RFA treatment, it is considered that PVs became reconnected, and complete recovery after re-insulation was reported in up to 90% of the selected patients (2).

It has been shown that arrhythmogenic focus forms in abnormal veins and the ablation of these veins could be used to successfully treat atrial arrhythmia (14). Therefore, mapping of PVs and identifying abnormal veins before the procedure are thought to be beneficial. Although before radiofrequency catheter ablation became an important treatment for atrial arrhythmia, pathology and surgical literature were not defined the variant pulmonary venous anatomy; thoracic surgeons were aware of the anatomical variations, such as the drainage of the right middle lobe into the lower PV, and that it might lead to destructive results during lower right lobectomy (15). Therefore, variations in pulmonary venous drainage were not well-defined until radiofrequency catheter ablation became an important treatment for atrial arrhythmia. Results of our study confirm that there are significant variations in pulmonary venous anatomy, particularly on the right side. In our series, the variation was on the right venous anatomy in 32% of the patients, and 25% of these patients had a separate orifice for the right middle lobe vein. In our series, the incidence of variant pulmonary venous anatomy is within the range of the studies that employed magnetic resonance imaging (MRI), ultrasonography, and CT scan (31%-38%) (2, 14, 16, 17). In previous studies on RFA, the focus was on the identification and mapping of four primary PVs (4, 18). However, these variations cannot optimally assess complex pulmonary venous anatomy most of the time (19, 20). Because of these reasons, cross-sectional images from CT or MRI can be requested before the ablation procedure.

Although angiography is the gold standard in imaging the pulmonary venous system, it has disadvantages, such as being invasive, causing radiation exposure to the patient and physician, and having a high cost. While transthoracic and transesophageal echocardiography enables imaging the left atrium, they are insufficient in showing the PVs. Therefore, the two noninvasive methods CT and MRI stand out in imaging the PVs and the left atrium (21, 22). In MRI, although the patient is not exposed to radiation, there are drawbacks, such as the long duration of the scan, motion artifacts, and claustrophobia. Moreover, MRI constitutes a contraindication for patients with metallic prostheses and implants. The PVCTA has advantages, such as a shorter duration, good patient compliance, and high-resolution images. The limitations of PVCTA include allergic reactions to the contrast agent, renal failure, and radiation.

Transverse, coronal, and coronal oblique images should be evaluate carefully in pulmonary anatomy investigation. This is because, in some complex situations, for instance, to show whether a vein opens into an orifice or into two closely located ostia, axial images are insufficient. A complex variant pulmonary anatomy can be seen in an easier manner in two- or three-dimensional reconstruction multiplanar images (1). Two- or three-dimensional reconstruction multiplanar images also reduce the radiation exposure of the patient and duration of the scan (1, 16, 23).

Pulmonary vein variations are significantly more prevalent in comparison to pulmonary artery variations. The number of ostia opening into the atrium, the location of the right lung middle lobe vein, and the fact that venous returns in both lung segments are not always into their own lobar veins are the reasons PV variations are more prevalent (24, 25).

Pulmonary vein variations were first defined systematically by Marom et al. (1) in the study published in 2004, which investigated the relationship between PVs and PVCTA with the left atrium and AF. This classification is alphanumeric and relies on the number of PVs opening into the left atrium and the position of the right lung middle lobe vein. According to Marom et al. (1) classification, the highest incidence belongs to L2A and R2A. Many limitations were reported in Marom et al. (1). First, because the CT scan performed on patients aimed to eliminate pulmonary embolism, it was reported that the results did not reflect the entire population. In addition, pulmonary venous anatomy is not expected to differ substantially between patients with suspected pulmonary embolism and the general population. In our study, thoracic and coronary CTAs were performed with various indications. Second, a very small patient group with atrial arrhythmia has been reported. In our study, patients could not be evaluated in terms of atrial arrhythmia. This study was prepared as an anatomical study.

Marom et al. (1) was interested in determining whether there was a relationship between any venous drainage pattern and atrial arrhythmia. Tsao et al. (14) reported a high incidence of variation in right middle lobe venous drainage in patients with refractory AF. In Marom et al. (1) study, sinus rhythm was observed in 70% of the patients in R2A and R2B right venous anatomy. One-half of the patients with atrial arrhythmia (50%) had typical venous anatomy. Values in Marom et al. (1) study were not statistically significant. Patients with R3A, R4A, R4B, and R5 types on the right (separate ostium for middle lobe PVs) were more prone to arrhythmia than other patients (18). A similar result was not found for left pulmonary anatomy, wherein there was no statistically significant finding between left variant anatomy and arrhythmia (1). There was no difference between gender distribution and drainage pattern in terms of arrhythmia ($p>0.155$). Similarly, in our study, there was no statistically significant relationship between female-male drainage patterns.

Marom et al. (1) stated that there were drawbacks because their classification was open to improvement. In addition, Marom et al. (1) provided a detailed explanation and drawing for each case that was investigated. We included the new patterns R5B that has five orifices on the right and L3 that has three orifices on the left in the classification as additions to Marom et al. (1) classification. Because R5B type was identified in two of 503 patients, it was not suitable for statistical evaluation. The variant structure defined as L3 on the left could not be compared with other groups in terms of the significance of gender distribution and its coexistence with other types on the right because it was identified in five (1%) patients. A larger series is required to achieve statistically significant results for the newly defined R5B and L3 types.

Yazar et al. (26) conducted a study on 30 cadavers in 2002 to investigate the drainage patterns of the right middle lobe vein and defined five drainage patterns of middle lobe vein. In type 1 (53.3%) and type 2 (16.6%), the middle lobe vein drains into the upper lobe vein; in type 3 and 4 (26.6%), the right middle lobe vein drains directly into the left atrium; and in type 5 (3.3%),the right middle lobe vein drains into the lower lobe vein (21). In our study, type 1-2 (R2A, R2B, R3B, and R3C) was seen in 70.5% of the patients, type 3 and 4 (R3A, R4A, R4B, R5A, and R5B) in 32.8% of the patients, and type 5 (R2C) in 4.8% of the patients. The type (R1) in which upper, middle and lower lobe veins open into the left atrium with a single ostium by forming a truncus was seen in 1.4% of the patients, and it was not reported in the previous study (26).

Right PV was seen in 16 patients (4%) in the study by Kaseno et al. (27) conducted in 2008 involving 428 patients. Lickfett et al. (28) reported the same to be 3%, whereas, in our study, RTPV was found in 17 (3.4%) of 503 patients.

In our study, apart from the classic anatomy involving L2A and L2B on the left, 35.2% of the patients had the anatomical types considered variants, whereas variations are less prevalent on the left side according to literature (1). Because of the similarity of left and right variation rates in our study, the left side should also be carefully evaluated in terms of variations.

In our study, L2B variation had the highest incidence on the left with a rate of 28.4%, wherein this variation was most frequently accompanied by R2B on the right. L1B had the second highest incidence with a rate of 25.6%, and in this variation, a lingular vein drained into the proximal inferior PV, and these two veins drained into the superior PV and opening into the left atrium. However, in the study of Marom et al. (1) including 201 patients, L1B was identified in only one patient.

Before the study by Marom et al. (1), variations in the number and structure of the PVs were only reported as case presentations (29, 30). Our study was based on the classification of Marom et al. (1). However, it reflects the general population because the scans were performed with different indications, and it is the largest study due to being conducted with 503 patients. Another importance of our study is that it reflects the variant pulmonary venous structures in the Turkish population.

CONCLUSION

Knowing the pulmonary venous anatomy before both RFA and surgical intervention is of utmost importance. MDCT is very beneficial in evaluating the variations in pulmonary venous drainage because it is noninvasive and easy to tolerate.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Gaziantep University (Approval Date: 27.03.2017; Approval No: 43).

Informed Consent: N/A

Peer-review: Externally peer-reviewed.

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