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Prevalence and Clinical Significance of Pulmonary Venous Orifice Variants

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ABSTRACT

Background: Awareness of pulmonary venous anatomy and variants is essential for diagnostic and interventional cardiology, especially in the scenario of atrial fibrillation ablation and cardiothoracic surgery. Even though the classical type of four discrete pulmonary venous orifices is the most prevalent, many anatomical variations have been described that could influence clinical results.

Objective: To evaluate the prevalence, morphology, and clinical implications of pulmonary venous orifice variants by imaging-based analysis in a regional patient population.

Methodology: A total of 65 patients were assessed to determine normal anatomy and variant patterns of pulmonary venous drainage. Variants examined were accessory pulmonary veins, common ostia, anomalous pulmonary venous return (PAPVR), and rare orifice anomalies. Prevalence rates were determined and contrasted with prior published studies. Data was analyzed using SPSS version 26.

Results: Normal anatomy with four discrete pulmonary venous orifices was found in 66.2% of patients. Variants were identified in 33.8% of cases, with accessory pulmonary veins (18.5%), the most frequent being the right middle pulmonary vein; common ostium formations (10.8%), with a predominance involving the left superior and inferior veins; partial anomalous pulmonary venous return (3.1%), with drainage into the superior vena cava and brachiocephalic vein; and one rare case (1.5%) of missing left inferior pulmonary vein orifice with fusion into the left superior pulmonary vein.

Conclusion: Pulmonary venous orifice variants are common and clinically relevant, with the right middle pulmonary vein and left common ostium being the most prevalent. Identification of these variants is necessary for proper imaging interpretation, secure operative planning, and successful catheter ablation procedures to prevent complications and recurrence of atrial arrhythmias.

Keywords: Pulmonary Veins; Anatomical Variants; Common Ostium; Atrial Fibrillation Ablation

Introduction

Pulmonary veins (PVs) are the important conduits down which oxygenated blood is carried from the lungs to the left atrium (LA), finalizing the pulmonary circulation and facilitating effective systemic delivery of oxygen. In most individuals, four discrete PVs i.e., right superior, right inferior, left superior, and left inferior drain separately into the LA, each via its own unique discrete orifice. This "classic" anatomical arrangement has long been considered the standard description in anatomy textbooks. However, advances in imaging modalities such as multidetector computed tomography (MDCT), cardiac magnetic resonance imaging (MRI), and intraoperative transesophageal echocardiography have revealed that variations in the number, size, and configuration of PV orifices are far more common than once appreciated. These variations, although often asymptomatic, carry profound clinical implications in cardiology, electrophysiology, and cardiothoracic surgery.[1]

Identification of the variant anatomy of PV orifices has increasingly become significant in the past few decades because of the development of pulmonary vein isolation (PVI) as the foundation of catheter ablation therapy for atrial fibrillation (AF). The pulmonary veins, especially at their border with the left atrium, are now well recognized as the most common sites for ectopic foci that initiate AF. Therefore, precise definition of PV anatomy is a prerequisite to planning and performing ablation procedures. The occurrence of accessory PVs, common ostia, or abnormal patterns of branching can render catheter navigation more difficult, enhance the risk of incomplete vein isolation, and make patients susceptible to recurrence of arrhythmias. In addition, slit-like or narrow orifices are linked to greater vulnerability to post-ablation pulmonary vein stenosis, a condition that may greatly compromise pulmonary venous drainage and result in dyspnea, hemoptysis, or pulmonary hypertension.[2]

Aside from electrophysiology, familiarity with PV variants is also surgically important. Cardiac and thoracic surgeons should also be cognizant of these patterns of anatomy during surgical procedures like lung resections, heart transplantation, or mitral valve surgery to prevent unintended injury, ligation, or mistaken identity of vessels. Similarly, identification of anomalous pulmonary venous return (partial or total) is critical in pediatric as well as adult cardiology since such an anomaly can cause left-to-right shunts, right heart enlargement, and pulmonary vascular disease in the absence of corrective treatment. Even apparently trivial discrepancies, like the occurrence of a right middle pulmonary vein or a common left ostium, change hemodynamic patterns of LA flow and impact long-term cardiovascular consequences.[3]

Traditionally, PV anatomy was described based on autopsy results and intraoperative observations, which granted limited appreciation of the range of variation. The development of high-resolution imaging has not only extended our knowledge of pulmonary venous anatomy but enabled quantification of its prevalence within large populations.[4] Recent literature has quantified that up to 30% of people present with an accessory pulmonary vein, the most frequent being a right middle pulmonary vein draining the middle lobe. Conversely, a shared ostium of the left superior and left inferior PVs occurs in 15–25% of cases. Less common yet clinically relevant anomalies are partial anomalous pulmonary venous return (PAPVR), more than one accessory vein, or fewer than four pulmonary veins. Taken together, these observations emphasize that so-called "normal" anatomy is seen in only approximately two-thirds of individuals, while a significant minority exhibit anatomical variation that can affect clinical practice.[5]

With these facts in mind, the investigation of variant anatomy of pulmonary venous orifices is no longer just an intellectual exercise in morphological description. Rather, it has become fundamental to patient care in contemporary cardiovascular medicine. Detailed knowledge of these variations enables correct diagnosis, maximizes procedural planning, reduces complications, and enhances therapeutic results in interventional and surgical procedures.

Objective

To evaluate the prevalence, morphology, and clinical implications of pulmonary venous orifice variants by imaging-based analysis in a regional patient population.

Methodology

This descriptive cross-sectional study was carried out at the department of Anatomy, Services Institute of Medical Sciences, Lahore. A total of 65 consecutive patients who underwent contrast-enhanced computed tomography (CT) of the chest or cardiac CT for various clinical indications were included. Inclusion criteria are adult patients (age ≥18 years) with contrast-enhanced cardiac or chest CT that both delineated the pulmonary venous anatomy well and had available complete Digital Imaging and Communications in Medicine (DICOM) files for analysis and reconstruction while Exclusion criteria are history of previous thoracic or cardiac surgery that could affect alternative pulmonary venous anatomy (lung transplantation, lobectomy) and Inadequate image quality because of motion artifact, suboptimal contrast opacification, or incomplete visualization of the pulmonary venous orifices.

Demographic information (age, gender, clinical reason for CT) was obtained from patient charts. Imaging results were listed, and prevalence of each pulmonary venous variant type was presented as percentages. Ostial

diameters were summarized as mean ± SD for continuous variables. Statistical analysis was performed using SPSS version 26.

Results

The study included a total of 65 patients who underwent evaluation of pulmonary venous orifices. The mean age was 52.4 ± 11.6 years (range: 28–74 years). When stratified by age groups, the majority of participants were between 40–59 years (50.8%), followed by ≥60 years (30.7%), while only 18.5% were younger than 40 years. There was a male predominance (56.9%) compared to females (43.1%), resulting in a male-to-female ratio of approximately 1.3:1. Regarding place of residence, urban dwellers constituted 63.1%, whereas 36.9% belonged to rural areas.

Educational background varied, with nearly half of the patients having higher education (49.3%), 36.9% with primary or secondary education, and 13.8% without formal education. Occupational status revealed that 43.1% were employed, 29.2% were unemployed or engaged in household duties, and 27.7% were retired. The mean body mass index (BMI) was 26.1 ± 3.8 kg/m^2. Based on BMI categories, 43.1% were overweight, 24.6% were obese, while 32.3% had normal weight.

With respect to lifestyle habits, 23.1% were current smokers, 15.4% were former smokers, and 61.5% had never smoked. Alcohol consumption was reported by only 9.2%, while the majority (90.8%) denied alcohol use. Analysis of comorbidities showed that hypertension was the most common (44.6%), followed by diabetes mellitus (26.2%), dyslipidemia (21.5%), coronary artery disease (16.9%), and chronic obstructive pulmonary disease (10.8%). Notably, 29.2% of patients had no significant comorbidities. A family history of cardiovascular disease was present in 33.8%, while 66.2% reported no such history (Table 1).

Among the 65 patients evaluated, the classical anatomical pattern of four distinct pulmonary venous orifices draining separately into the left atrium was observed in 43 patients (66.2%), making it the most common finding. Anatomical variants were identified in 22 patients (33.8%). The most frequent variation was the presence of accessory pulmonary veins, detected in 12 patients (18.5%). The majority of these were right middle pulmonary veins (RMPV), with occasional right upper lobe (RUL accessory) and left upper lobe (LUL accessory) additional veins.

A common ostium, defined as the fusion of superior and inferior pulmonary veins on the same side, was observed in 7 patients (10.8%). Of these, the left superior and inferior pulmonary veins (LS+LI) merging into a single ostium was the predominant type, while right-sided common ostium (RS+RI) was less frequent. Anomalous pulmonary venous drainage was noted in 2 patients (3.1%), consistent with partial anomalous pulmonary venous return (PAPVR). In these cases, pulmonary veins drained into systemic venous structures such as the superior vena cava (SVC) or the left brachiocephalic vein (BCV) instead of the left atrium. A rare anomaly was found in 1 patient (1.5%), who demonstrated only three pulmonary venous orifices due to absence of a separate inferior pulmonary vein orifice, with venous return occurring via a common trunk (Table 2).

Out of 65 patients, 12 (18.5%) demonstrated accessory pulmonary veins. The majority were located on the right side, with the right middle pulmonary vein (RMPV) being the most frequent subtype, observed in 9 patients (75.0% of accessory veins; 13.8% of the total cohort). In all these cases, the RMPV drained independently into the left atrium, separate from the right superior and inferior pulmonary veins. Two patients (16.7% of accessory veins; 3.1% of total) exhibited an additional right upper lobe (RUL) accessory vein, which drained separately from the right superior pulmonary vein (RSPV). On the left side, a single case (8.3% of accessory veins; 1.5% of total) of an accessory left upper lobe (LUL) vein was identified. This small-caliber vein was observed to drain the anterior segment of the left upper lobe directly into the left atrium, distinct from the left superior pulmonary vein (LSPV) (Table 3).

A total of 7 patients (10.8% of the study population) demonstrated common ostium formation of pulmonary veins. The vast majority were observed on the left side, where fusion of the left superior and left inferior pulmonary veins (LSPV + LIPV) was identified in 6 patients (85.7% of common ostia; 9.2% of the total cohort). These left-sided common ostia were typically wide, funnel-shaped openings draining directly into the left atrium.

A right-sided common ostium, involving confluence of the right superior and right inferior pulmonary veins (RSPV + RIPV), was noted in 1 patient (14.3% of common ostia; 1.5% of the total population). This variant presented as a relatively oval-shaped orifice, smaller in caliber compared to left-sided common trunks (Table 4).

Partial anomalous pulmonary venous return (PAPVR) was identified in 2 patients (3.1% of the study population). On the right side, 1 patient (1.5%) demonstrated drainage of the right upper lobe pulmonary vein into the superior vena cava (SVC) instead of the left atrium. This variant presented as a well-formed anomalous channel coursing vertically towards the SVC, consistent with classical PAPVR morphology. On the left side, 1 patient (1.5%) exhibited drainage of the left upper lobe pulmonary vein into the left brachiocephalic vein (BCV). The anomalous vein joined the BCV at its superior aspect, bypassing the left atrium entirely (Table 5).

A rare anatomical variation was identified in 1 patient (1.5% of the study population). In this case, the left inferior pulmonary vein (LIPV) lacked an independent orifice, instead merging with the left superior pulmonary vein

Table 1. Demographic and Clinical Characteristics of the Study Population (n = 65)

Variable	Category/Value	Number (n)	% of total
Age (years)	Mean ± SD	52.4 ± 11.6	–
	Range	28 – 74	–
Age groups	<40 years 40–59 years ≥60 years	12 33 20	18.5% 50.8% 30.7%
Sex	Male Female	37 28	56.9% 43.1%
Residence	Urban Rural	41 24	63.1% 36.9%
Education level	No formal education Primary/secondary Higher education	9 24 32	13.8% 36.9% 49.3%
Occupation	Employed Unemployed/household Retired	28 19 18	43.1% 29.2% 27.7%
BMI (kg/m²)	Mean ± SD Normal weight (18.5–24.9) Overweight (25–29.9) Obese (≥30)	26.1 ± 3.8 21 28 16	– 32.3% 43.1% 24.6%
Smoking status	Current smoker Former smoker Never smoker	15 10 40	23.1% 15.4% 61.5%
Alcohol consumption	Yes No	6 59	9.2% 90.8%
Comorbidities	Hypertension Diabetes mellitus Coronary artery disease COPD Dyslipidemia None	29 17 11 7 14 19	44.6% 26.2% 16.9% 10.8% 21.5% 29.2%
Family history of CVD	Present Absent	22 43	33.8% 66.2%

Table 2. Distribution of pulmonary venous anatomy in 65 patients

Category	Subtype	n	% of total
Normal anatomy	Four separate orifices	43	66.2%
Accessory pulmonary veins	RMPV, RUL accessory, LUL accessory	12	18.5%
Common ostium	LS+LI or RS+RI	7	10.8%
Anomalous venous drainage	PAPVR to SVC/BCV	2	3.1%
Other rare variants	Three orifices only	1	1.5%

(LSPV) to form a single common trunk draining into the left atrium. Morphologically, this variant presented as a broad, elongated orifice that accommodated venous return from both the superior and inferior pulmonary lobes on the left side. While functionally adequate, this fusion pattern eliminated the presence of a discrete inferior pulmonary vein ostium (Table 6).

Discussion

The anatomy of pulmonary venous orifices is extremely important in clinical practice and interventional cardiology. While the traditional configuration is four distinct pulmonary veins draining separately into the left atrium, there have been many different anatomical variations reported in imaging and autopsy studies. These heterogeneities are becoming increasingly appreciated with widespread application of multidetector computed tomography (MDCT), magnetic resonance imaging (MRI), and intra-procedural mapping during atrial fibrillation ablation.[6] In this current study of 65 patients, we categorized and reported pulmonary venous orifice variants such as accessory veins, common ostia, and anomalous patterns of venous drainage, thus gaining important insights into their prevalence and clinical relevance.

The average age of our study group was 52.4 ± 11.6 years, and the majority of participants were aged 40–59 years (50.8%). This is in agreement with prior studies of patients who underwent pulmonary venous imaging or atrial fibrillation ablation. For example, Kato et al. (2003)[7] indicated a mean age of 54 years in their multidetector CT imaging series of atrial fibrillation patients' pulmonary venous anatomy, whereas Bhargava K et al. (2007)[8] noted a comparable mid-fifties age predominance in their cohort undergoing ablation. These observations imply that the age at which pulmonary venous variants are most frequently assessed coincides with the usual age range for atrial arrhythmias and their comorbidities. In sex distribution, our cohort consisted of males at 56.9%, a finding echoed by Marom et al. (2004),[9] who illustrated a predominance of males (about 60%) in their CT-based analysis of pulmonary venous anatomy. Equivalently, Ho et al. (2001)[10] stressed that though anatomical differences are not sex-related, the prevalence of men in clinical series must logically represent the greater incidence of atrial fibrillation and ischemic heart disease in men. The urban dominance (63.1%) in the present study is striking, South Asia and the Middle East have similarly seen a greater percentage of urban patients in hospital-based imaging series, possibly because they have better access to tertiary care centers and not because there is an epidemiological difference.[3]

The education level reported in the present study revealed

Table 3. Accessory pulmonary veins (n = 12)

Laterality	Type of accessory vein	N	% of accessory veins	% of total (n=65)	Morphological notes
Right	Middle pulmonary vein	9	75.0%	13.8%	Independent drainage into LA
Right	Upper lobe accessory	2	16.7%	3.1%	Additional RUL vein, separate from RSPV
Left	Upper lobe accessory	1	8.3%	1.5%	Small vein draining anterior LUL

Table 4. Common ostium variants (n = 7)

Laterality	Type of common ostium	N	% of common ostia	% of total (n=65)	Morphological notes
Left	Left superior + inferior PVs (LSPV+LIPV)	6	85.7%	9.2%	Single wide orifice
Right	Right superior + inferior PVs (RSPV+RIPV)	1	14.3%	1.5%	Oval-shaped ostium

that almost half (49.3%) were educated to higher levels, and just 13.8% did not have any formal education. This trend is different from larger community-based research in South Asia but is consistent with increased literacy and awareness in hospital-based imaging.[2] In comparison to BMI, the average value of 26.1 kg/m² was in the overweight range, and almost 67.7% of the participants were overweight or obese. This is consistent with evidence from Lioni L et al. (2011)[11], where a high rate of overweight status was shown among Japanese patients undergoing ablation of atrial fibrillation. The expanding association between obesity and atrial arrhythmogenesis has been highlighted in several studies, such as Wong et al. (2010)[12], where it was proven that obesity not only contributes to the risk of atrial fibrillation but also affects procedural results. Smoking status within our cohort indicated that 23.1% were active smokers and 61.5% had never smoked. Similar distributions were also found by Marrouche et al. (2002)[13], where about one-quarter of atrial fibrillation ablation patients were active smokers. Equivalently, low alcohol intake (9.2% in our research) is representative of the cultural trends of South Asia but is contrary to Western research like Takami et al. (2015)[14], where alcohol was a more significant variable among atrial arrhythmia patients. Among comorbidities, hypertension (44.6%) was seen most frequently, followed by diabetes mellitus (26.2%) and dyslipidemia (21.5%). This profile is similar to the report by Lin et al. (2009)[15], who reported hypertension in 48% and diabetes in 22% of patients referred for ablation procedures in Taiwan. Likewise, Haïssaguerre et al. (1998)[16] reported hypertension and ischemic heart disease as frequent comorbidities among patients with atrial fibrillation associated with pulmonary venous triggers. Lastly, a history of cardiovascular disease in first-degree relatives was noted in 33.8% of our study group. Though not consistently described in pulmonary venous reports, family history has been identified as a predictor for atrial fibrillation and coronary artery disease in population studies, including Fox et al. (2004)[17] in the Framingham Heart Study.

In our series of 65 patients the typical four discrete pulmonary venous orifices were seen in 43 patients (66.2%), whereas anatomic variations were seen in 22 (33.8%) accessory veins (18.5%), common ostia (10.8%), PAPVR (3.1%), and infrequent patterns (1.5%). These prevalences are within range in modern imaging series, though the precise prevalences differ among studies based on patient populations (general CT populations vs AF ablation referrals), image acquisition, and definition types. Some CT and cross-sectional imaging studies report accessory right middle lobe veins as the solitary most frequent variant with broadly variable prevalence estimates (≈10–25%). Wang Z et al. (2021)[3] reviewed pulmonary vein variants in a surgical/imaging series and noted direct outflow of the middle lobe vein in ~25% of cases, highlighting that right-sided accessory drainage is common and relevant to thoracic procedures. Our prevalence of accessory veins (18.5%, RMPV 13.8% of total) is consistent with this trend. More recent 3D-CT classification studies have further delineated the right middle pulmonary vein (RMPV). Wei et al. (2023)[18] provided detailed morphologic subtypes of RMPV and reported high rates of RMPV variants in a large cohort, reinforcing that the right lung frequently contributes accessory ostia and that detailed preprocedural mapping is necessary for safe ablation or resection. The predominance of right-sided accessory veins in our series is consistent with Wei's observations. Common ostium (confluent superior + inferior PVs) prevalence in literature shows variability. Left-sided common ostia (left common

Table 5. Anomalous pulmonary venous drainage (n = 2)

Laterality	Variant type	N	% of total (n=65)	Drainage site	Morphological description
Right	PAPVR	1	1.5%	Superior vena cava	Right upper lobe vein draining to SVC
Left	PAPVR	1	1.5%	Left brachiocephalic vein	Left upper lobe vein draining to BCV

Table 6. Rare pulmonary venous orifice variants (n = 1)

Laterality	Variant type	N	% of total (n=65)	Morphological description	Clinical note
Left	Absent inferior PV orifice	1	1.5%	LIPV merged with LSPV, forming single trunk	Important for ablation planning

ostium / long left trunk) are frequently described, and many recent cohorts describe left common ostium frequencies in the ~5–15% range. Common ostia appeared in 7/65 (10.8%) in our sample with left-sided predominance, consistent with other recent CT-based cohorts which have attributed left common ostium to AF pathophysiology as well as to technical reasons during pulmonary vein isolation. Research targeting outcomes following ablation has directly examined left common ostium as a modifier of procedure success.[18]

Partial anomalous pulmonary venous return (PAPVR) is typically uncommon in unselected CT series (reported prevalences typically <1% but variable depending on cohort and detection). Rahnama et al. (2022)[19], in a CT registry review with a large population, reported on PAPVR detected in ~0.2% of reports of chest CT, observing that most are incidentally detected. Our 2 cases (3.1%) exceed population CT registries possibly because our imaging population is enriched for patients referred for cardiac evaluation (including workup for AF) where venous mapping was conducted this selection effect makes it more likely to find clinically significant venous anomalies. In the current series, 12 patients (18.5%) had accessory pulmonary veins.

The right middle pulmonary vein (RMPV) was the most frequent subtype, observed in 9 patients (75.0% of accessory veins, 13.8% of overall series), followed by right upper lobe accessory veins in 2 patients (16.7%), and a unique case of left upper lobe accessory vein (8.3%). Morphologically, the RMPV drained separately into the left atrium, whereas the accessory RUL veins were isolated from the RSPV, and the left-sided accessory vein drained a small anterior segment of the upper lobe. These results are strongly concordant with earlier imaging-based and anatomical research such as Marom et al. (2004),[9] where in a multidetector CT analysis of 201 patients, accessory pulmonary veins were observed in 24% of patients, the RMPV being the most common variant (19%). Likewise, Sherif HM et al. (2013)[20] have reported accessory veins in around 20% of their population once more with a dominance of RMPV. Electrophysiology-focused research has highlighted the procedural significance of accessory veins. Kato et al. (2003)[7] illustrated that unacknowledged drainage of RMPV can lead to recurrence of atrial fibrillation following ablation unless isolated, pointing to the necessity of meticulous preprocedural imaging. For left-sided accessory veins, Ho et al. (2001)[10] noted that further smaller veins originating from the left upper lobe are less frequent (<5%), typically draining anterior or apical segments. The one case found in our study (1.5%) conforms to this reduced frequency. Rodriguez-Manero M et al. (2015)[21] also underscored the fact that left-sided accessory veins tend to be small-caliber and easily missed on standard imaging, but could potentially bear arrhythmogenic foci. In the current cohort, variants of common ostium were seen in 7 patients (10.8%), most of which presented on the left side (LSPV + LIPV, 85.7%), while a case was seen on the right side (RSPV + RIPV, 14.3%).

The left-sided variant is usually presented as a solitary wide orifice, while the right-sided variant had an oval-shaped ostium. These results are in accordance with previous anatomical and imaging investigations such as Marom et al. (2004),[9] who, in a large CT-based series, stated that left superior and inferior pulmonary veins common ostium was the most prevalent PV variant, present in as much as 14–25% of patients. Likewise, Sherif HM et al. (2013)[20] noted that a left common ostium was found in close to 20% of their electrophysiology population undergoing ablation. Conversely, right-sided common ostium (RSPV + RIPV) has been reported to be less common. Ho et al. (2001)[10] reported a prevalence of approximately 2–5%, consistent with the isolated case (1.5% of overall cohort) identified in this study. Kato et al. (2003)[7] also highlighted that right-sided forms are uncommon but clinically significant, since the oval-shaped ostium can predispose to deranged flow dynamics and might complicate transcatheter ablation approaches. The morphological features noted in this research a wide orifice in left-sided types and oval shape in the right-sided type are likewise consistent with reports by Sherif HM et al. (2013)[20] who noted that left common ostium morphology is generally funnel-shaped and wide, whereas right-sided fusions are elongated. Collectively, our results confirm earlier reports of the left common ostium being the prevalent form, and right-sided fusion being rare but worthy of identification owing to possible procedural considerations in electrophysiology and surgery. Partial anomalous pulmonary venous return (PAPVR) was identified in 2 patients (3.1%) during the present series, one on the right side (RUL vein draining into the superior vena cava) and one on the left side (LUL vein draining into the left brachiocephalic vein).

Both cases morphologically showed a solitary anomalous vein with normally draining venous of the rest of the lobes. These results are consistent with earlier anatomical and imaging literature such as Lin et al. (2009)[15], in an autopsy

series, initially reported the incidence of PAPVR to be around 0.4–0.7% in the general population. More recent CT-based reports have documented slightly greater prevalence as a result of enhanced imaging resolution such as Marom et al. (2004)[9] detected PAPVR in approximately 0.4% of cases, whereas Ho et al. (2001)[10] described prevalence rates reaching 0.7–0.9% within clinical series. In accordance with our findings, the right-sided PAPVR draining into the SVC is the most frequently reported subtype. Rodriguez-Manero M et al. (2015)[21] pointed out that the right upper lobe vein draining into the superior vena cava is the classic and most common type. However, left-sided PAPVR, including the left upper lobe vein draining into the brachiocephalic vein, is not common but has been consistently reported. Sherif HM et al. (2013)[20]and Ammash & Seward (1997)[22] pointed out this variant and mentioned its significance in surgical planning, especially in the presence of other associated congenital anomalies like sinus venosus atrial septal defect. Our study's prevalence of 3.1% is slightly greater than in large series (≤1%), which could be due to the relatively small sample size or better detection with detailed imaging. Significantly, Ho et al. (2001)[10] and Jujo T et al. (2016)[23] emphasized that PAPVR is regularly underdiagnosed on routine imaging unless meticulously assessed, implying that actual prevalence in prior studies could be misjudged. We identified in our series a rare variant of pulmonary venous orifice in 1 patient (1.5%), featuring the absence of a distinct left inferior pulmonary vein (LIPV) orifice, with the LIPV joining the LSPV to give rise to a single common trunk.

This rare pattern is clinically relevant for catheter ablation, as venous ostia misidentification or partial isolation may set the stage for arrhythmia recurrence. Earlier anatomical and imaging researches have, at times, reported similar observations such as Marom et al. (2004)[9], in a big CT study, observed that though left common ostium (LSPV + LIPV) is quite common (up to 14–25%), complete lack of a discrete LIPV orifice is uncommon and seen in only a small number of patients. Also, Sherif HM et al. (2013)[20] reported bizarre pulmonary venous configurations, such as when the inferior vein did not exist as an isolated ostium. From an electrophysiological standpoint, Kato et al. (2003)[7] and Mansour M et al. (2004)[24] pointed out that these variants make isolation of the pulmonary veins technically challenging, since extensive area ablation may be necessary to include the common trunk. Ho et al. (2001)[10] also highlighted that not recognizing uncommon variants can enhance the risk of incomplete isolation or accidental ablation of surrounding structures. Case-report based descriptions also attest to clinical significance such as Rodriguez-Manero M et al. (2015)[21] described isolated findings of missing LIPV orifices, underscoring the importance of preprocedural imaging using CT or MRI for precise mapping of venous anatomy. Jujo T et al. (2016)[23] also reported rare PV trunk anomalies on pre-ablation evaluation, highlighting their procedural implications. Hence, our findings are consistent with the literature suggesting that LSPV and LIPV fusion into a single trunk is uncommon (<2%) but with significant clinical implications, especially in the planning of ablation procedures to achieve long-term rhythm control.

Conclusion

This research proves that pulmonary venous orifice variations are quite frequent, as almost one-third of patients had abnormalities from the typical four-orifice anatomy. The most common variations found were accessory pulmonary veins, especially the right middle pulmonary vein, then common ostium formations, partial anomalous pulmonary venous return, and infrequent anomalies like absent inferior pulmonary venous orifice. From a clinical standpoint, identification of these variants is critical for precise interpretation of imaging, surgical planning, and electrophysiological interventions. Procedural failure to detect anomalous or variant venous drainage can result in procedural complications, inaccurate pulmonary vein isolation, or recurrence of arrhythmias. Multidetector CT and MRI are advanced imaging techniques that play a critical role in preprocedural mapping and risk stratification.

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