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Morphological and morphometric study of pulmonary vein anatomy in relation to cardiac invasive and electrophysiological procedures

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Abstract: Pulmonary veins (PVs) and their myocardial sleeves play an important role in the development of atrial fibrillation. Hence, detailed knowledge of PV anatomy is required to improve the procedural success rate and prevent complications during cardiac procedures. The aim of this study was to evaluate the PV anatomy along with anatomical variations in the Indian population. Total 100 formalin fixed cadaveric hearts were examined. The number and pattern of the PVs were observed along with the measurement of their horizontal and vertical diameters. The ovality index for each PV was calculated. Classical PV pattern was observed in 62% cases. Variant pattern like additional right middle PV pattern and left common PV pattern were found in 20% and 10% cases respectively. A separate pattern with presence of both right middle PV and left common PV was observed in 6% cases. In the classical pattern right superior PV was the largest followed by right inferior, left superior and left inferior PV. The additional right middle PV had the smallest diameter whereas the left common PV had the largest diameter. Almost all the veins had greater vertical diameters in comparison to horizontal diameters. The variant PVs were oval and had greater ovality index compared to the normal PVs. In classical pattern 54.8% hearts whereas in variant pattern 79% hearts had one or more oval PV. The given data can help clinicians for planning and execution of various interventional and electrophysiological procedures involving PVs.

Key words: Pulmonary veins, Atrial fibrillation, Left atrium, Radiofrequency catheter ablation

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Introduction

The pulmonary veins (PVs) are important blood vessels which transport oxygenated blood from the lungs to the left atrium of the heart. They open into the posterolateral surface of the left atrium more superiorly. The openings of PV are round to oval in shape and are usually four in number.

The PV anatomy and arrangement inside the left atrium can interfere with the direct access of the left atrium to practicing clinicians. Hence, prior knowledge of the PV anatomy can be helpful in the exposure of this cavity. The openings of right sided PVs are found beside the atrial septum and thus, care must be taken while working in this region.

The PVs contain myocardial sleeves which are thin extensions of the atrial myocardium which cover their distal part. These myocardial sleeves play a major role in the development of supraventricular arrhythmias, particularly atrial fibrillation [1]. The atrial-PV junction also contains substrate of chronic atrial fibrillation [2]. Hence, PVs are important sites of focus for interventional cardiologists and electrophysiologists.

Variations are commonly found in PV anatomy. The variation in the pattern of pulmonary venous openings is

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due to over or under absorption of the common PV during development. The possibility of developing atrial fibrillation might be affected by the different patterns of pulmonary venous openings [3].

The treatment of atrial fibrillation involves radiofrequency catheter ablation (RFCA) procedures like PV isolation [4]. It has been suggested that larger PV size is associated with more recurrent atrial fibrillation after PV isolation and hence prior determination of PV diameter before procedures may predict its success [5].

The venous ostium index or ovality index is used to determine whether a PV opening is oval or circular. Circular catheter used for isolation of oval PV may result in unsuccessful ablation due to its affected stability and position [6].

Detailed knowledge of PV anatomy guides the physicians in the selection of correct catheter size and ablating the correct ectopic points during RFCA procedure and helps improve the procedural success rate and prevent complications [7].

Despite increased cases of atrial fibrillation, there hasn't been much study on the PV morphology in the Indian population. Hence, this study is aimed to provide crucial anatomical data to various practicing cardiac interventionalists and electrophysiologists.

Materials and Methods

This study was conducted in the Anatomy Dissection lab. In this study, total one hundred formalin fixed adult cadaveric heart specimens irrespective of age, sex, and race were collected from the Anatomy Department of various medical colleges in Central Gujarat region. Cadaveric hearts with anatomical damage or pathological conditions were excluded. The research protocol for conducting this study was approved by the Institutional Ethics Committee of GMERS Medical College and Civil Hospital, Sola, Ahmedabad (reference no. GMERSMCS/IEC/44/2022).

All the hearts were dissected from the thoracic cavity along with proximal parts of the great vessels like superior vena cava, inferior vena cava, pulmonary arteries, PVs and ascending aorta. The blood clots were removed, and the hearts were cleaned properly. Then, specimens were selected randomly.

The study took place by observing the left atrium grossly followed by internal examination. First, the left atrium was viewed from the posterior aspect and the pattern and numbers of PVs were noted. For internal examination, a horizontal and two vertical incisions were made in the region between the left and right sided PV in the posterior wall of the left atrium. Then, this flap-like incision was turned inferiorly, and if blood clots present were removed.

The findings about pulmonary venous pattern obtained externally were confirmed by looking at the number and position of different pulmonary venous ostia from the inner aspect. The hearts were classified into various patterns on the basis of number of PV openings into the left atrium. It was followed by measurement of the transverse and vertical diameters of the PVs in anatomical position. All the diameters were measured in same manner and plane to avoid errors. For measurement purpose Zhart digital caliper 150 mm (Zhart) was used. This device has an accuracy of 0.02 mm. The diameters were measured by placing the internal measuring jaws of the electronic caliper in between the two opposite sides of the opening at the veno-atrial junction. The ovality index was calculated by taking the ratio of maximum diameter and minimum diameter. Ovality index greater than 1.2 was considered to be oval and less than 1.2 was considered round [8]. The mean values along with standard deviation were determined using simple mathematical tools.

Results

Classical PV pattern (having normal four PV openings) was observed in 62 hearts (62%) (Fig. 1). Variant patterns

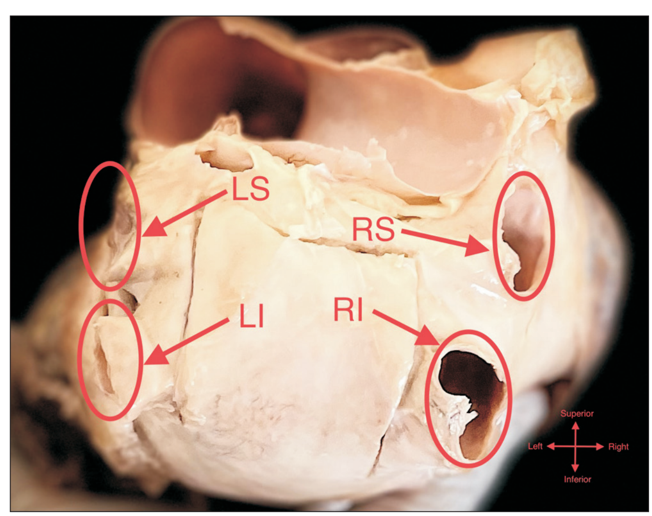

Fig. 1. Classical 4 PV pattern. PV, pulmonary vein; LS, left superior; LI, left inferior; RS, right superior; RI, right inferior.

Table 1. Pulmonary vein variant patterns observed in the study

Group	Hearts (%)
Classical four PV pattern	62 (62)
Additional right middle PV pattern	20 (20)
Left common PV pattern	10 (10)
Left common PV with additional right middle PV pattern	6 (6)
Two additional middle veins (left and right) pattern	2 (2)

PV, pulmonary vein.

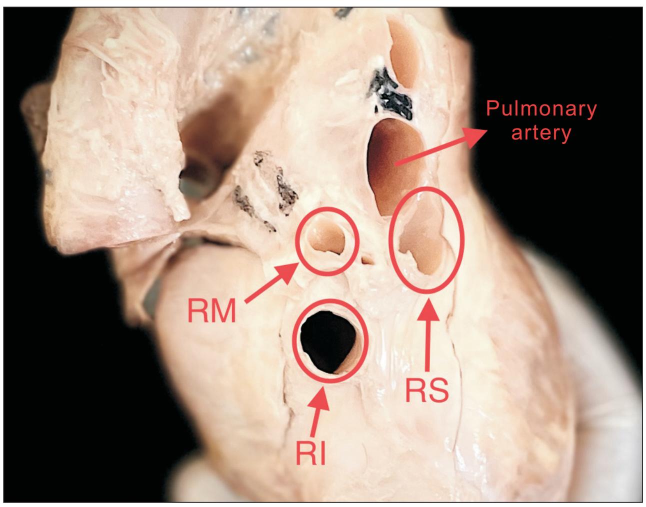

Fig. 2. Additional middle right PV pattern. PV, pulmonary vein; RS, right superior; RM, right middle; RI, right inferior.

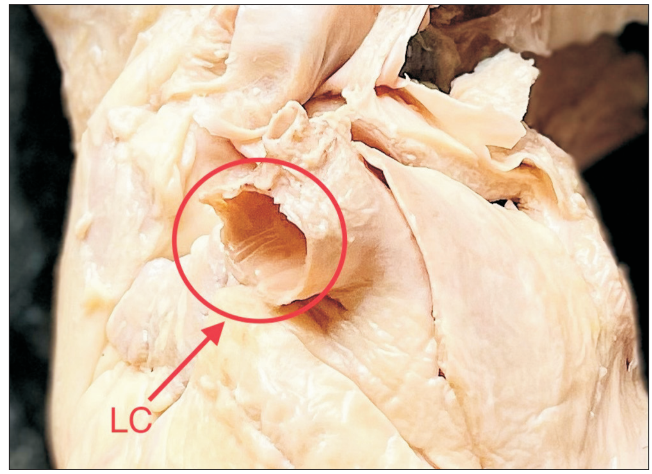

Fig. 3. Left common PV pattern. PV, pulmonary vein; LC, left common.

(other than classical PV pattern) were observed in 38% hearts. Table 1 shows all the PV patterns observed in the study. The most common variant PV pattern was the presence of additional right middle PV along with classical four PV in 20% cases (Fig. 2). Common ostium for left superior and left inferior PV along with right superior and right inferior PV was observed in 10% cases (Fig. 3). A separate variant PV pattern having additional right middle PV and left common PV together was identified in 6% cases. 2% hearts had additional middle PV on both right and left sides.

According to individual variations in PVs, additional right middle PV was seen 28% cases, left common PV in 16% cases and additional left middle PV in 2% cases. Right sided PV variations were more common than left sided PV variations.

In the classical PV pattern the mean diameters of right and left superior PV ostia were greater than right and left inferior PV ostia respectively. It was also observed that the mean diameters of the right superior and right inferior PV ostia were greater than the left superior and left inferior PV ostia respectively. In the additional middle PV pattern the mean diameters of both right superior and inferior PV ostia were found less than that of classical PV pattern. The additional right middle PV ostium had the smallest whereas the common left ostium had the greatest mean diameter in comparison to all PV ostia. Tables 2 and 3 show mean diameters of all PV ostia according to pattern.

In the classical pattern right sided PVs were more oval compared to left sided PVs and right inferior PV was the most oval vein. Variant PV like additional right middle PV and left common PV had greater ovality index and were more oval compared to the normal veins. Table 4 shows the mean ovality index and prevalence of oval PVs across different patterns.

In classical pattern, 54.8% hearts had one or more oval PV where as 79% variant hearts had one or more oval PV (Table 5).

Discussion

The anatomy of PV is important for planning various cardiac procedures because they act as an important source of ectopic beats and generates arrhythmia. Variations are frequently seen in the number and pattern of PV.

The classical PV pattern was seen in 62% of the total specimens. Previous studies have noted the prevalence of the classical PV pattern in 68%–77% cases [9-15]. Variant PV anatomy has greater prevalence in patients of atrial fibrillation [10, 16-18]. In our study variant PV anatomy was found

Table 2. Mean and standard deviation of horizontal diameters of pulmonary vein ostia

Group	PV	Horizontal ostium diameter (mm)			
		Mean	SD	Minimum	Maximum
Classical 4 PV pattern	Left superior	14.41	1.40	10.39	17.10
	Left inferior	13.03	1.54	9.70	16.66
	Right superior	15.73	2.48	7.98	20.21
	Right inferior	14.64	2.64	9.47	22.49
Additional middle right PV pattern	Left superior	14.99	3.10	10.47	19.02
	Left inferior	13.55	1.82	11.07	16.80
	Right superior	12.65	1.63	9.89	15.94
	Right inferior	12.79	2.20	10.17	17.74
	Additional right middle	7.95	1.69	5.29	10.01
Left common PV pattern	Common left	18.63	3.76	15.69	25.61
	Right superior	16.02	1.03	14.97	17.24
	Right inferior	13.56	2.02	10.39	15.52
Left common PV with additional right middle PV pattern	Common left	17.63	0.23	17.35	17.91
	Right superior	13.06	0.65	12.59	13.90
	Right inferior	12.15	0.88	11.17	13.18
	Additional right middle	6.08	0.75	5.18	6.89

PV, pulmonary vein.

Table 3. Mean and standard deviation of vertical diameters of pulmonary vein ostia

Group	PV	Vertical ostium diameter (mm)			
		Mean	SD	Minimum	Maximum
Classical 4 PV pattern	Left superior	14.98	1.54	10.59	18.84
	Left inferior	13.92	1.94	10.06	19.14
	Right superior	17.08	3.64	8.27	26.90
	Right inferior	16.54	2.83	9.98	26.01
Additional middle right PV pattern	Left superior	14.20	2.74	9.96	19.21
	Left inferior	13.83	2.19	10.76	17.40
	Right superior	13.60	2.01	11.25	16.63
	Right inferior	14.61	3.10	10.49	22.04
	Additional right middle	9.51	2.49	6.80	13.41
Left common PV pattern	Common left	20.21	2.63	17.76	24.90
	Right superior	16.67	1.04	15.79	18.58
	Right inferior	13.41	2.05	10.90	16.81
Left common PV with additional right middle PV pattern	Common left	22.40	2.99	18.99	25.73
	Right superior	13.65	0.67	12.76	14.21
	Right inferior	14.05	0.71	13.36	14.94
	Additional right middle	7.72	2.36	4.85	10.10

PV, pulmonary vein.

in a significant 38% cases.

The right middle PV is a commonly found variant and it contains additional myocardial sleeves. These sleeves play role in the development of atrial fibrillation. Hence, this variant has higher chances of occurrence of atrial fibrillation compared to others [10]. In our study this variant was found in 28% cases. Hence, clinicians must be familiar with this variant. Another variant found was the presence of a single common ostium on the left side (left common PV) in 16% cases. Studies have shown that during cryoablation procedures patients with left common ostium variant have worse prognosis compared to normal PV anatomy [19, 20]. Thus, proper identification of this variant by imaging must be done prior to cryoablation and treated carefully.

The diameters of the PV are important to physicians to select the correct catheter size for ablation. Both large and

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Table 4. Prevalence of oval veins in different patterns with mean ovality index

Group	PV	Percentage of specimens with oval veins (≥1.2)	Mean ovality index
Classical 4 PV pattern	Left superior	16.13	1.11
	Left inferior	12.90	1.12
	Right superior	25.81	1.12
	Right inferior	25.81	1.14
Additional middle right PV pattern	Left superior	40.00	1.20
	Left inferior	0	1.07
	Right superior	10.00	1.10
	Right inferior	30.00	1.16
	Additional right middle	40.00	1.19
Left common PV pattern	Common left	60.00	1.22
	Right superior	0	1.10
	Right inferior	40.00	1.15
Left common PV with additional right middle PV pattern	Common left	66.00	1.27
	Right superior	0	1.05
	Right inferior	33.00	1.16
	Additional right middle	33.00	1.30

PV, pulmonary vein.

Table 5. Hearts with one or more oval pulmonary vein according to pattern

PV pattern	Hearts with 1 or more oval PVs (%)
Classical 4 PV pattern	54.8
Additional right middle PV pattern	70.0
Left common PV pattern	100.0
Left common PV with additional right middle PV pattern	67.0
Two additional middle veins (left and right) pattern	100.0

PV, pulmonary vein.

small PV diameters are frequently associated with difficult ablation and unsuccessful procedures. PVs having larger diameters have larger circumference with higher electrophysiological abnormalities [5]. In the present study in classical pattern superior PVs had greater diameters than inferior PVs and also right sided PVs had greater diameters than left sided PVs. Larger PV size is associated with increased recurrence of atrial fibrillation [15, 21]. Various studies have found that large PVs have increased risk and incidence of stenosis during cryoballoon ablation [22-24]. In our study the left common PV had the largest diameter among all the PVs. Clinicians should focus on these larger PVs to achieve their proper isolation. We also found that when an additional middle vein was present on the right side the diameters of right superior and right inferior PVs decreased compared to the classical pattern. This was also observed in study by Piotrowska et al. [11]. Smaller PVs are also associated with stenosis during RFCA procedure [25]. We observed that the additional right middle PV had the smallest diameter and such small sized veins can be missed out during imaging. PVs having smaller diameters cannot be occluded using the standard 28 mm cryoballoon and require additional smaller 23 mm cryoballoon for proper ablation. This leads to increase in procedure time [26].

PV ostia do not have uniform shape. They may be circular or oval. The PV ovality index is frequently used to assess the shape of the PV ostium. In our study most PVs were oval in shape and had greater vertical diameters compared to their horizontal diameters. Previous studies have showed that left sided PVs are more oval than right sided PVs [7, 27-29]. Contrary to this in our study in classical pattern right sided PVs were more oval than the left sided PVs. During cryoablation procedure the right inferior PV is the most difficult vein to isolate due to its position relative to the catheter [30, 31]. In our study this vein had the maximum ovality index. This may make the complete isolation of right inferior PV more difficult in the Indian population. We also found that the variant PVs like additional middle right PV and left common PV had a higher ovality index compared to the normal veins and similar results were seen in previous study [7]. Oval veins were more prevalent in variant pattern hearts (79%) compared to classical pattern hearts (54.8%). Increased ovality leads to incomplete ablation using circular catheter and cryoballoon because of their insufficient contact with the PVs [6]. Hence the physician must take care when working with such variant oval PVs.

In conclusion, only 62% of hearts had the classical four

PV pattern and the remaining 38% hearts had variant PV anatomy. The additional right middle PV was the most common variant followed by the left common PV. Among all the PV the additional middle right vein had the smallest diameter and left common vein had the largest diameter. In all the PVs vertical diameters were greater than the horizontal diameters. Also, the variant PVs were more oval in comparison to the classical PVs. The given data can help clinicians for planning and execution of various interventional and electrophysiological procedures.

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Author Contributions

Conceptualization: HO, BD. Data acquisition: HO, BD. Data analysis or interpretation: HO, BD. Drafting of the manuscript: HO, BD. Critical revision of the manuscript: HO, BD. Approval of the final version of the manuscript: all authors.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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