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Original Research Article

The Variations of the Pulmonary Ostia and the number of pulmonary veins in the Left Atrium relative to the position of Fossa Ovalis: A Cadaveric Study

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ABSTRACT

Background: Atrial fibrillation is the most common arrhythmia, with pulmonary veins playing a key role in its initiation. The isolation of pulmonary vein is the preferred treatment for paroxysmal atrial fibrillation so a detailed anatomical knowledge of pulmonary veins is essential.

Purpose of the study: The present study aims to document the draining patterns of pulmonary veins and their distance from the fossa ovalis.

Methodology: In routine dissection done for undergraduate students an observative study was done on 38 adult cadaveric hearts to determine the variations in number of pulmonary veins, differences in the size of pulmonary ostia and their location with respect to the fossa ovalis.

Results: Out of 38 cadaveric hearts dissected, 10 (26.3%) deviated from the classical 4 Pulmonary vein pattern. 2.6% were Type IIa, IIIa, and Vb, 73.7% were Type IVa, 10.5% were Va and 7.9% were unclassified.

Conclusion: The knowledge of these variations of pulmonary veins is of great clinical importance due to the increase of interventional procedures that require access to left atrium such as catheter ablations and valvular repairs.

KEYWORDS: Atrial fibrillation, pulmonary vein ostia, fossa ovalis, left atrium.

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BACKGROUND

The left atrium of the heart receives oxygenated blood from the lungs via pulmonary veins. Pulmonary veins originate from the capillary network and end at the left atrium. Typically, there are four pulmonary veins—two from each lung, consisting of one superior and one inferior pulmonary vein—that carry oxygen-rich blood to the left atrium. These veins enter the left atrium on its posterolateral surface through two distinct pulmonary ostia on either side [1].

During early embryonic development the cardiac development is inseparably associated with development of embryonic venous system. The embryonic vasculature consists only of bilaterally paired vitelline veins, situated between the endoderm of the yolk sac and the splanchnopleuric mesoderm. These vitelline veins fuse in the midline and form a ventral vessel [2,3]. With further growth of the embryo proper, the cardinal and umbilical venous systems and for those species relying on oxygenation of blood, pulmonary veins are formed [4], Fig.1. During this stage of development of vessels and their connection to the heart, many malformations of the cardiac in flow have their origin and can result in abnormalities ranging from simple deformities across fossa ovalis to complex malformations involving the variations in the drainage of pulmonary vein. These differences can lead to the presence of supernumerary veins or common trunks, influencing both normal pulmonary venous return and the electrical conduction pathways.

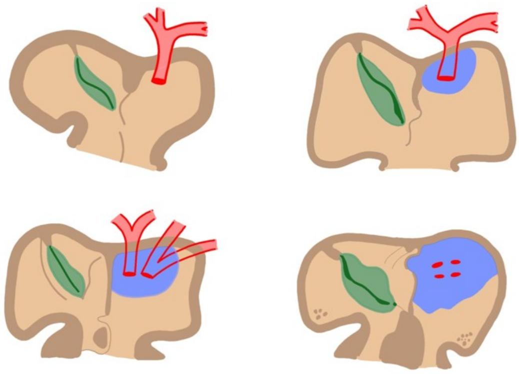

Fig. 1: Development of pulmonary veins at A.5 weeks B. 51/2 weeks C. 6 weeks and D.8 weeks Adapted from B.M.Carlson 5th edition.

Pulmonary veins play a key role in the pathogenesis of atrial fibrillation [5]. Atrial fibrillation is the most common arrhythmia and it represents a major cause of mortality and morbidity, mainly to embolic events and heart failure [6]. The mechanisms underlying atrial fibrillation are classically described as mechanisms responsible for initiation (triggers) and mechanisms responsible for perpetuation [7]. Various studies confirmed the role of pulmonary veins in triggering atrial fibrillation [5,8,9]. Pulmonary vein (PV) isolation has become the most widely used technique for treatment of paroxysmal Atrial fibrillation [10]. Also, the knowledge of pulmonary vein anatomy variants allows an appropriate preoperative radiological assessment and safe surgical management of vascular anomalies in patients undergoing major lung resections like in segmentectomy [11].

Based on the number of pulmonary veins and pulmonary ostia in the left atrium on the right and left sides separately, a classification was suggested by Shukla et al. It will be helpful for the clinicians to evaluate the anatomy of pulmonary veins prior to or during any procedures involving these veins. Also, it will also facilitate communication regarding the pulmonary veins with their co-workers. Depending upon the number of pulmonary veins, it may be classified into Type I to Type V. If the number of Pulmonary ostia is equal to the number of Pulmonary veins, it may be categorized into A subtype and if the number of Pulmonary ostia is less than the number of Pulmonary veins, then it may be categorized into B subtype.[12] (Fig1a)

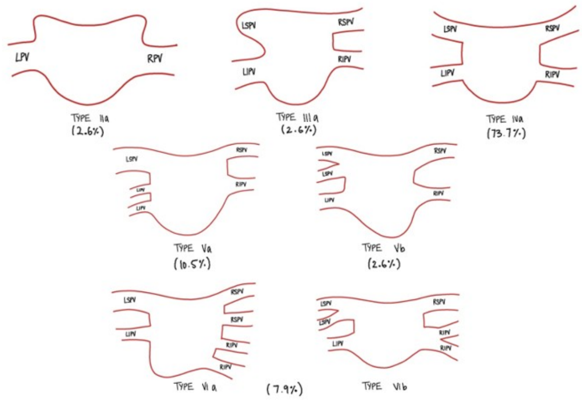

Figure 1a: Diagrammatic representation of drainage pattern of Pulmonary veins based on number of Pulmonary veins and pulmonary ostia observed in the present study.

MATERIALS AND METHODS

This descriptive study was conducted in the department of Anatomy at KMCH Institute of Health Sciences and Research, Coimbatore for a period of six months in the year 2024 after getting ethical clearance from Institutional Ethics Committee. Using a convenient sampling technique, 38 well-fixed, formalin-preserved hearts from routine dissections were examined. Initially all the great vessels were evaluated for any malformations. An inverted U-shaped incision was made on the posterior wall of the left atrium with scissors, ensuring the pulmonary veins were not damaged. The number of pulmonary veins was determined after locating the left atrial chamber. The number of pulmonary ostia were then counted. The draining patterns of the pulmonary veins were classified according to Shukla et al. system (**Table 1**), and observed the

Table 1: Shukla et al classification of drainage pattern of Pulmonary vein based on number of Pulmonary veins and pulmonary ostia [13].

Type - Right/Left	Number of Pulmonary veins and number of ostia
Type I	1 Pulmonary vein with 1 ostium
Type II a	2 Pulmonary veins with 2 ostia
Type II b	2 Pulmonary veins with 1 ostium
Type III a	3 Pulmonary veins with 3 ostia
Type IIIb	3 Pulmonary veins with less than 3 ostia
Type IV a	4 Pulmonary veins with 4 ostia
Type IV b	4 Pulmonary veins with less than 4 ostia
Type V a	5 Pulmonary veins with 5 Ostia
Type V b	4 Pulmonary veins with less than 4 ostia

incidence based on their relation to the pulmonary ostia as shown in **Table 2**. The maximum transverse diameter of each pulmonary ostium was measured using Digital Vernier callipers. Additionally, the distance from the centre of each pulmonary ostium to the upper margin of the fossa ovalis was measured using measuring tape. These measurements were noted and tabulated as part of the descriptive study (**Table 3**). Photographs were taken. Numerical analysis was performed using Microsoft Excel worksheet. Data was presented as number of cases and frequency.

Table 2: Displays the draining patterns of pulmonary veins in the hearts included in the study (n=38).

Type of hearts according to Shukla et al 2012 [13]	Number(n)	Incidence Percentage (%)
Type Ia	0	0
Type IIa	1	2.6
Type IIb	0	0
Type IIIa	1	2.6
Type IIIb	0	0
Type IVa	28	73.7
Type IVb	0	0
Type Va	4	10.5
Type Vb	1	2.6
Unclassified	3	7.9
Total	38	100

RESULTS

Of the 38 cadaveric hearts dissected, 10 (26.3%) hearts exhibited deviated pattern from the classical IV pulmonary vein pattern. Type IIa, IIIa, and Vb were 2.6%, 73.7% were Type IVa, 10.5% were Va and 7.9% were unclassified (Table - 2, Fig : Ia, 2-8). The average diameters of pulmonary vein ostia in the classical Type IVa were Right Superior Pulmonary vein RSPV (1.6cm ± 0.6cm SD), LSPV – Left Superior Pulmonary vein (1.3cm ± 0.4cm SD), (RIPV) Right Inferior Pulmonary Vein (1.1cm ± 0.4cm SD), and LIPV Left Inferior Pulmonary Vein (1cm ± 0.2cm SD).

The mean distance from the pulmonary veins to the upper margin of the fossa ovalis in Type IVa was Right superior pulmonary vein to Fossa ovalis RSPV- FO (2.7cm ± 0.8cm SD), Left Superior Pulmonary Vein to Fossa ovalis LSPV- FO (3.9cm ± 0.9cm SD), Right Inferior Pulmonary Vein to Fossa ovalis RIPV- FO (1.7cm ± 0.7cm SD), and Left Inferior Pulmonary Vein to Fossa ovalis LIPV- FO (3.6cm ± 0.8cm SD). The measurements of variant patterns were described in Table 3 & 4.

Fig. 2: Showing Type IIa pattern with single large RPV and single large LPV.

Table 3: Showing the diameters of Right and Left Superior and Inferior Pulmonary ostia in variant hearts excluding Type IVa . (ERPV1 – Extra Right Pulmonary vein 1, ERPV2 – Extra Right Pulmonary vein 2, ELPV – Extra Left Pulmonary vein).

S.no.	Distance between RSPV - FO	Distance between LSPV - FO	Distance between RIPV - FO	Distance between LIPV - FO	Distance between ERPV1 - FO	Distance between ERPV2- FO	Distance between ELPV1- FO	Type of heart according to Shukla et al. 2012 [13]
1	3.2	2.7	2.8	4	3			Type Va
2	2.2	3.6	1.3	4.9	0.6			Type Va
3	2.6	4	2.4	3.8				**Unclassified (VIb)**
4	0.9	4.6						Type IIa
5	2.8	3.9	3	2.5				**Unclassified (VIb)**
6	3.2	2.7	2.8	4	3	3.6		**Unclassified (VIa)**
7	1.9	2.6	1.7	3.3			3.4	Type Va
8	2.8	4	1.5					Type IIIa
9	3.6	5.5	2.2	2.9				Type Vb
10	3.6	4.8	1.7	3.3	2.8			Type Va

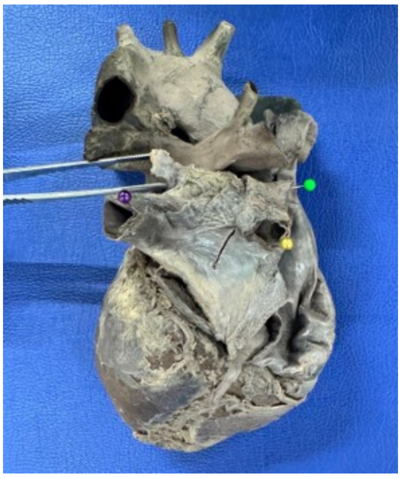

Fig.5a: Showing Type Va pattern with RSPV, RIPV, large LSPV and 2 LIPV.

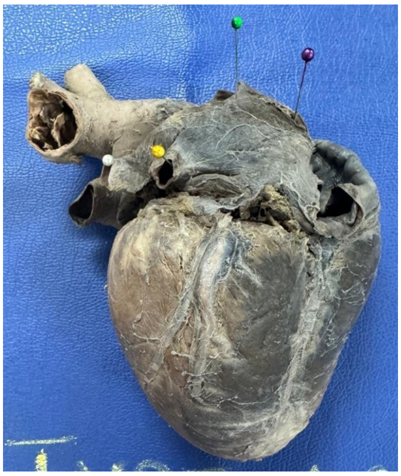

Fig. 4: Showing Classical Type IVa pattern with RSPV, RIPV, LSPV, LIPV.

Fig. 3: Showing Type IIIa pattern with single large LIPV, RSPV, RIPV, Atretic LSPV.

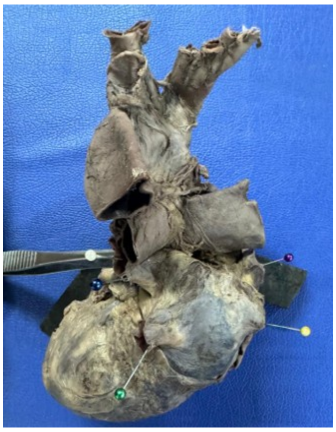

Fig.5b: Showing type Vb pattern with RSPV, RIPV, 2 LSPV with common ostia and LIPV.

Fig. 6: showing Type VIa pattern with 2 RSPV, 2 RIPV, large LSPV and LIPV (unclassified).

Fig. 7: Showing Type VIb pattern with RSPV, 2 RIPV with common ostia, 2 LSPV with common ostia and LIPV (unclassified).

Fig. 8: Showing the method used to measure the distance between middle of a pulmonary ostia and upper margin of fossa ovalis on the septal wall of the left atrium.

Table 4: Showing the distance of variant pulmonary vein from the upper margin of fossa ovalis in variant hearts.

S.no	Diameter of RSPV ostia	Diameter of LSPV ostia	Diameter of RIPV ostia	Diameter of LIPV ostia	Diameter of ERPV1 ostia	Diameter of ERPV2 ostia	Diameter of ELPV ostia	Type of heart according to Shukla et al. 2012 [13]
1	0.7	1.2	1.6	1.1	0.5			Type Va
2	0.9	1.4	1.9	1.2	0.6			Type Va
3	1.3	1.2	1.7	0.9				**Unclassified**
4	3	2.8						Type IIa
5	0.7	1.4	1.6	1.1				**Unclassified**
6	1	0.6	0.4	0.2	1.2	1.7		**Unclassified**
7	1.3	0.7	0.9	1.8			1.2	Type Va
8	1.6	0.9	1.2					Type IIIa
9	1.9	0.4	1.5	1.2				Type Vb
10	1.6	1.7	1.1	1.2	0.5			Type Va

(RSPV- Right Superior Pulmonary Vein; LSPV – Left Superior Pulmonary Vein; RIPV-Right Inferior Pulmonary Vein; LIPV – Left Inferior Pulmonary Vein; ERPV1- FO – Extra Right Pulmonary Vein1 to Fossa Ovalis; ERPV2- FO- Extra Right Pulmonary Vein 2 to Fossa Ovalis; ELPV1- FO - Extra Left Pulmonary Vein 1 to Fossa Ovalis).

DISCUSSION

The variations in the number of pulmonary vein ostia in the left atrium was thought to be rare [14]. The basic anatomy of pulmonary veins forms a pivotal role in both normal cardiac function and in the pathogenesis of Atrial Fibrillation [7]. The most essential details required non-invasively before the procedure for an interventional cardiologist include the number, position, and dimensions of the pulmonary veins, along with any branching anomalies, which would guide the choice of catheter size for the intervention technique. The duration of the radiofrequency ablation technique can be made shorter if the pre-procedural mapping is thorough.

In the present study, the classical four-pulmonary-vein pattern (Type IVa) was observed in 73.7% of specimens, consistent with existing literature reporting this pattern in 60–80% of cases. However, a significant proportion (26.3%) of hearts displayed variations in number and drainage pattern, highlighting the importance of recognizing these anatomical deviations in clinical practice. Kubala et al. in their study found that individuals with a Typical IV pulmonary vein pattern had better clinical outcomes than those with a left common ostia [15]. Many cardiologists, radiologists and cardiothoracic surgeons examined the normal anatomy of pulmonary veins and left atrium because of different types endovascular and surgical methods used for the treatment of Atrial fibrillation. Kato et al in their research reaffirm the presence of variations of pulmonary veins similar to the present study [16]. Variant Pulmonary patterns, including additional right or left pulmonary veins, and the presence of common trunks, may alter the atrial substrate and are clinically relevant during radiofrequency ablation procedures for paroxysmal AF. The presence of extra pulmonary veins or common trunks may complicate isolation procedures and require tailored catheter approaches. Notably, we observed a Type IIa pattern with a large Right common pulmonary vein ostium (3 cm), which contrasts with Bonczar et al who reported the largest diameter in the Left common pulmonary vein [17]. Since there isn't a strong consensus on the structure of the pulmonary vein, more research with larger groups is definitely required.

Atresia, which refers to the lack of or decreased openings of pulmonary veins into the left atrium of the heart, occurs infrequently. Unilateral congenital absence of a single pulmonary vein is uncommon and rarely identified during infancy. The likelihood of identifying the absence of a single pulmonary vein increases when pulmonary hypo-development is accompanied by an infiltrative pattern in the interstitial part of the lung parenchyma. Cardiac catheterization is the definitive method for diagnosis, enabling confirmation of whether the pulmonary veins are atretic or stenotic, and it also aids in evaluating and potentially treating anticipated complications.

The measured distances between the pulmonary vein ostia and the upper margin of the Fossa ovalis (FO) are of particular importance for electrophysiologists, especially during transeptal puncture and mapping procedures. The RSPV-FO distance (mean 2.7 ± 0.8 cm) and LSPV-FO distance (3.9 ± 0.9 cm) in the classical pattern offer useful anatomical landmarks for procedural navigation.

Furthermore, myocardial sleeves extending into the proximal segments of Pulmonary veins, particularly the superior veins, have been identified as critical sites for ectopic electrical activity triggering Atrial Fibrillation. Histologically, these sleeves contain myocardial fibres that are capable of automaticity and conduction [9]. Few studies have proposed the presence of pacemaker-like cells including Cajal-like cells within the walls of pulmonary veins, potentially contributing to their arrhythmogenicity. The mile stone in the treatment of Atrial fibrillation was considered to be the Circumferential pulmonary vein isolation regardless of the AF form and of the AF duration. No ablation strategy reliably demonstrated superior to pulmonary vein isolation in preventing recurrences on long term basis for atrial arrhythmias [18].

It indicates that although PV muscle covers a large extent of PV perimeter, there are specific breakthrough(s) from the left atrium that allow ostial PV disconnection with minimal ablation [6].

Bose P et al in their study, found 3-5 ostia on right side in 16% of heart samples, while a single ostium was observed on left side in 2.67% of hearts, but no accessory left sided pulmonary vein was observed [19]. 3 hearts were associated with the single unilateral pulmonary veins on the left side of the left atrium according to Mani Kathapillai et al [20]. The Present study supports these findings, with 10 hearts (26.3%) showing deviations from the classical pattern. Interestingly, some variant hearts also showed altered spatial orientation, with extra pulmonary veins located at variable distance from the Fossa ovalis.

Past studies have shown that Multi slice Computed tomography and Cardiac Magnetic Resonance are effective, non-invasive, widely available methods for mapping the structure of the left atrium and the connections of pulmonary veins in patients who qualify for ablation therapy [21].

The pulmonary veins can be considered as image biomarkers of atrial fibrillation. The right additional pulmonary vein was the most common anomaly detected in AF patients as well as enlarged diameters of the LA and PV ostia [21]. In contrast to this study Type IVa variety's extrapulmonary veins were more prevalent on the left side. However, the unclassified type (Type VIa) appeared more on the right side, which is consistent with the current investigation.

In summary, this study underscores the importance of comprehensive preoperative imaging and anatomical understanding of PV patterns and their relation to intra-atrial landmarks. Such knowledge is essential to optimize outcomes in interventional cardiology, electrophysiology, and cardiothoracic surgery.

CONCLUSION

The study of the pulmonary veins is of great use to assess the blocked, clotted vessels at the end of the catheter ablation. The irregularities of the abnormal pulmonary veins can resemble a pulmonary arteriovenous malformation in chest x ray images. So, thorough preoperative evaluation by radiologists is very much essential to perform and interpret pulmonary vein mapping examinations, whether done with CT or MRI. This is considered to be an important factor that may change the operator's approach, modify the therapeutic strategy and reduce periprocedural complications and Pulmonary Vein Isolation efficacy.

Abbreviations:

AFib - Atrial fibrillation
PV - Pulmonary vein
PVI - Pulmonary vein Isolation
RSPV - Right Superior Pulmonary Vein
LSPV - Left Superior Pulmonary Vein
RIPV - Right Inferior Pulmonary Vein
LIPV - Left Inferior Pulmonary Vein
ERPV1- FO - Extra Right Pulmonary Vein1 to Fossa Ovalis
ERPV2- FO - Extra Right Pulmonary Vein 2 to Fossa Ovalis
ELPV1- FO - Extra Left Pulmonary Vein 1 to Fossa Ovalis
CT - Computed Tomography
MRI - Magnetic resonance imaging

Author Contributions

Mrs. Sobana M is the principal investigator involved in the data collection and study conduction. Analysis and preparation of the manuscript were assisted by **Dr. Sakthivel M** and **Dr. Vijaianand M. Dr. Geeta Anasuya D** supervised the study and helped in writing and correction of the manuscript.

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Conflicts of Interests: None

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