Left ventricular summit – concept, anatomical description and clinical significance

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Abstract

In recent times the left ventricular summit (LVS) has become an interesting heart region. This triangular epicardial area is a ventricular arrhythmias source with a high level of difficulty for radiofrequency ablation. Providing systematic and comprehensive anatomical terminology of the LVS region may facilitate the exchanging of information among anatomists and electrophysiologists, increasing knowledge over this heart region. We will provide new anatomical terminology such as the apex of the left ventricular summit, arcuate line, septal margin, and mitral margin, as well as present a recent state of basic – scientific knowledge from this heart region.

Introduction

In recent times the left ventricular summit (LVS) has become an interesting heart region. This triangular epicardial area is a ventricular arrhythmias source with a high level of difficulty for radiofrequency ablation [1]. There are various approaches for reaching LVS arrhythmias, while the proximity to target the arrhythmia source might be challenging [2]. Important anatomical structures, such as surrounding coronary arteries, epicardial fat, and fibrotic components, may complicate the approach [3]. Another aspect is an estimation of LVS size, which depends on the first septal perforator's distance. A recently conducted analysis depicts the area size and neighboring structures of LVS using computer tomography [4]; however, there has been no proposition of complex anatomical terminology for LVS.

LVS definition and anatomy

The LVS is the most superior portion of the epicardial left ventricle region, surrounded by the bifurcation of the left coronary artery, left anterior descending artery and circumflex artery, termed by McAlpine in 1975 [5]. A delineation by an arched line, with the radius of this arc as the distance from the bifurcation of the left coronary artery to the first septal perforator, is representative of the most inferior boundary of this region.

Inside this trigon, the great cardiac vein transitions from the left atrioventricular groove towards the anterior atrioventricular groove as the anterior interventricular cardiac vein. The great cardiac vein bisects the LV summit into a superior area, also named the inaccessible area and inferior area – the accessible area for RF ablation [2]. According to these anatomical boundaries, LVS is a triangular or even "pizza slice" shape with an apex, base, and left and right margin. Each margin has a specific relation to the adjacent anatomical structures, and each is named and described [Figure1].

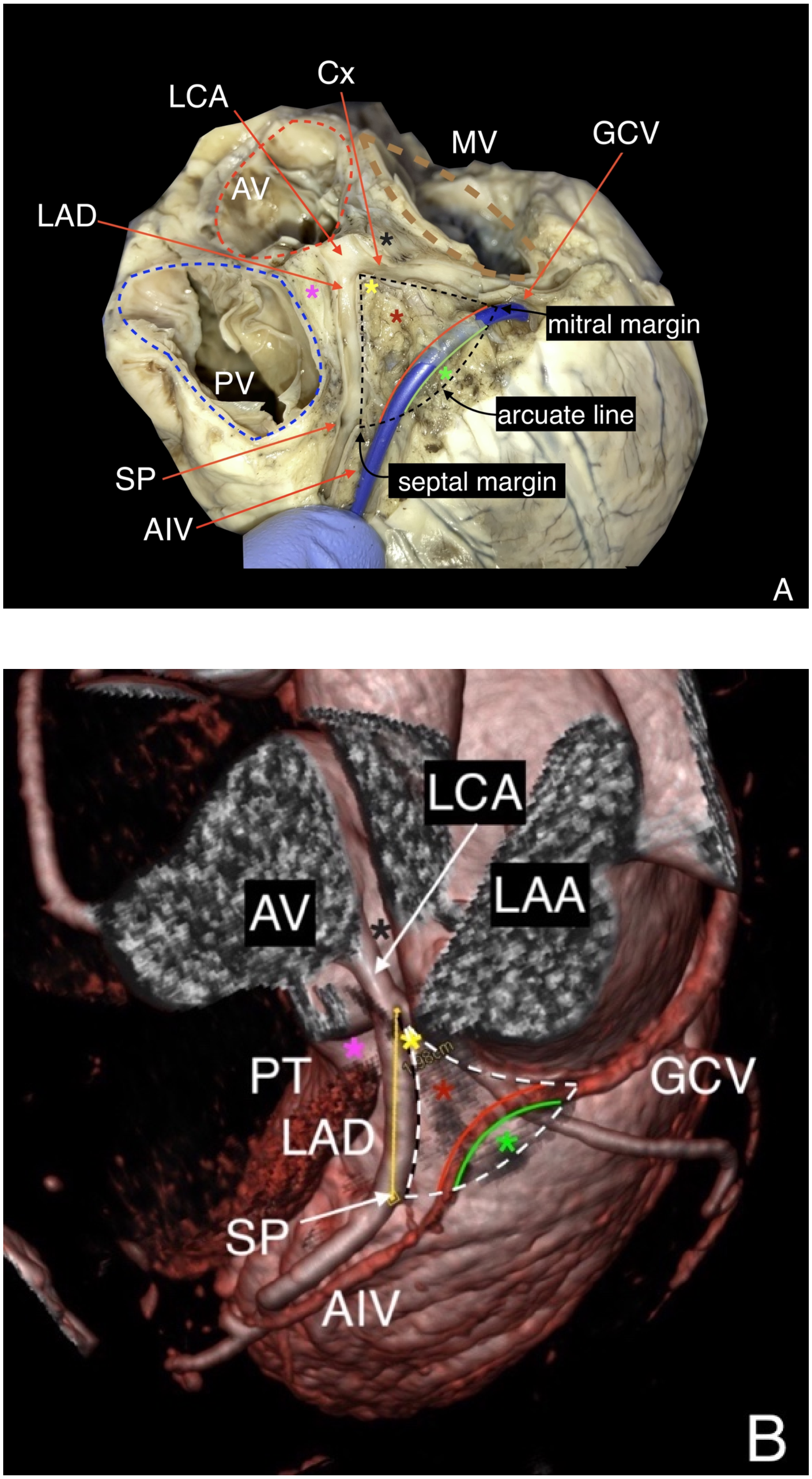
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Figure 1 A – left ventricular summit in gross dissection at the level of the fibrous skeleton of the heart, B – LVS in an angio-CT rendered image. **Abbreviations:** LVS = left ventricular summit; LAD = left anterior descending artery; LCA – left coronary artery; Cx = circumflex branch of left coronary artery; GCV = great cardiac vein; AIV = anterior interventricular vein; SP= septal perforator; LAA = left atrial appendage; PT = pulmonary trunk, PV pulmonary valve, MV – mitral valve, AV – aortic valve. red asterisk – inaccessible area; green asterisk accessible area; violet asterisk - septal summit; black asterisk – aortiomitral continuity; yellow asterisk – apex of LVS.

LVS apex

The direction of the apex of the LVS is superiorly towards left coronary artery ostium and starts at the point of bifurcation of the left coronary artery to the circumflex branch of the left coronary artery and left interventricular branch of the left coronary artery. The mean distance from the LVS apex to the left coronary artery ostium is approximately 10mm [4,11]. The nearest neighboring structure to the LVS apex is the aortic root, covered by a large fibrous structure – the aorto–ventricular membrane [5]. The aortic root is the continuation of the left ventricle outflow tract and occupies a central position within the heart, located to the right and posteriorly, relative to the subpulmonary infundibulum [2]. The apex, into the deep of the myocardium, correlates with the left aortic sinus (sinus of Valsalva), septal summit to the right, and aortomitral continuity left [Figure 1A, B]. Covering it superficially is the epicardial adipose tissue and partially the pulmonary trunk [Figure 2A]. The localization of the LVS apex is dependent on the left coronary artery trunk length, and it's bifurcation to main branches, starting from the ostium up to 21mm. Approximately 10% of the left coronary artery trifurcates, and from the apex, the ramus intermedius penetrate the LVS area, trespassing in the midsection over the accessible and inaccessible areas. In almost 2% of cases, the apex may not be present in the absence of the left coronary artery when the circumflex branch of the left coronary artery originates from the left sinus of Valsalva. Among patients with bicuspid aortic valves, this percentage is double [11].

Right margin of LVS – septal margin

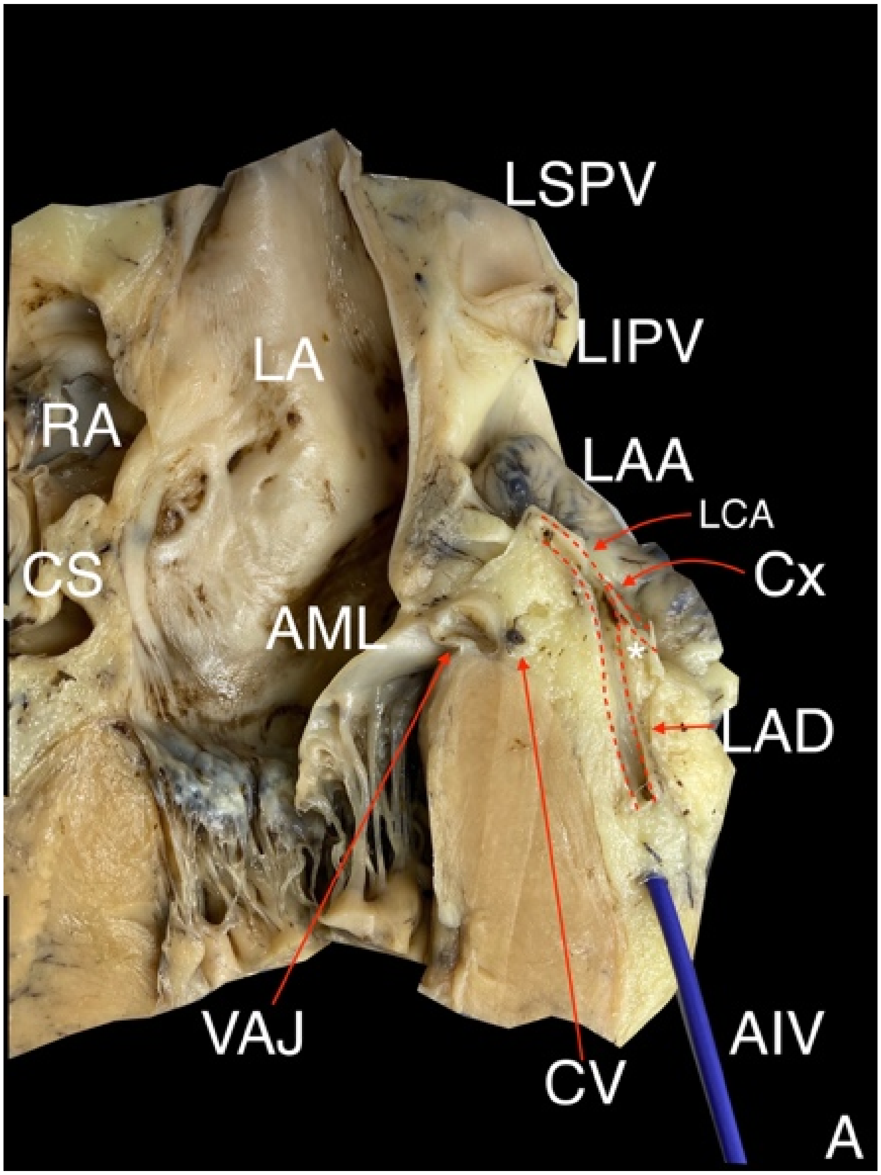
The anterior interventricular groove and structures lying inside the left anterior descending artery and anterior interventricular vein determine the right boundary of the LVS. The relation between those vessels in the majority presents a profound intersection of the anterior interventricular vein to the left anterior descending artery (54,4%) [6]. Along the artery and vein, the left coronary cardiac nerve form the left coronary subplexus is distributed to contribute to the autonomic innervation of the left ventricle [25]. The right margin corresponds with the pulmonary trunk, nevertheless between the right aspect of the anterior interventricular groove and pulmonary trunk, a few millimeters of the septal summit, or the septal aspect of LVS is present. That is why the name of the right margin of LVS should be considered as a "septal margin." This term's first usage was in a recent Liao publication describing ventricular arrhythmias with abrupt R-wave transitions in V3[20]. The measurement from the bifurcation of the left coronary artery to the first dominant septal perforator denotes the length of the septal margin of the LVS. The annulus of the pulmonary valve and pulmonary trunk, above the septal margin of LVS are present. These structures are overlying the LVS in the most superior aspect. The right ventricle output truck correlates with the lower portion of the septal margin, and various amounts of epicardial adipose tissue between those structures are present [figure2C]. From the septal margin of LVS, the first or sometimes second diagonal branch enters into the LVS region, while toward the ventricular septum, septal perforators are penetrating. The anterior interventricular vein enters from the anterior interventricular groove into the LVS. In some cases, when the most dominant septal perforator is more proximal to the left coronary artery bifurcation, the anterior interventricular vein may not cross the septal margin of LVS. The most uncommon variation is the anterior interventricular vein's right turn, becoming the anterior cardiac vein [7]. What is worth mentioning is the possible presence of the myocardial bridges. Their presence is not so uncommon and varies from 41.3 – 89.4% over the anterior interventricular branch of the left coronary artery, however, they present mainly below the border of LVS. Extracting data from Kosiński and Grzybiak the possible presence varies from 3-4% if the myocardial bridge is present while generally this amount reaches 1% [29].

Left Margin of LVS – mitral margin.

The left coronary groove delineates the left boundary of LVS with the circumflex branch of the left coronary artery and the initial section of the great cardiac vein. In some cases, the circumflex branch of the left coronary artery is accompanying the conus vein, which trespasses under the trunk of the left coronary artery (Figure 2A, B) while almost inevitable is presence of left lateral cardiac nerve (Figure 4E) [28]. The length of the mitral margin is equal to the septal margin. This margin neighbors close to the left fibrous trigon, the mitral annulus (anterior mitral leaflet), left atrium, and inlet into the left atrial appendage (LAA) [6]. The LAA overlaps the mitral margin, most commonly covering around 80% of it. In some cases, the mitral margin's superior aspect may be covered by the pulmonary trunk or left main pulmonary artery [4]. The first or sometimes, the second obtuse marginal branch from the left coronary artery's circumflex branch enters into LVS from the mitral margin. The great cardiac vein directing the heart's base enters over a mitral margin of LVS into the left coronary groove. At this point, the great cardiac vein is more often superficial to the coronary arteries (61,2%) than in other parts of LVS [6]. The left phrenic nerve trespassing epicardially over LAA, directing to the left dome of the diaphragm, may cross the mitral margin [8].

Base of LVS – arcuate line

The The delineation by a curved line, with the radius of this arc as the distance from the bifurcation of the left coronary artery to the first septal perforator, denotes the most inferior boundary LVS [3]. Creating a line over the left ventricle's epicardial surface, often perforated by trespassing ramus intermedius, diagonal, and obtuse marginal branches [Figure 2B, 4A]. Also, the venous system with the anterior interventricular vein may cross the arcuate line. The amount of epicardial adipose tissue along the arcuate line is significantly smaller than in other aspects of LVS [Figure 2B



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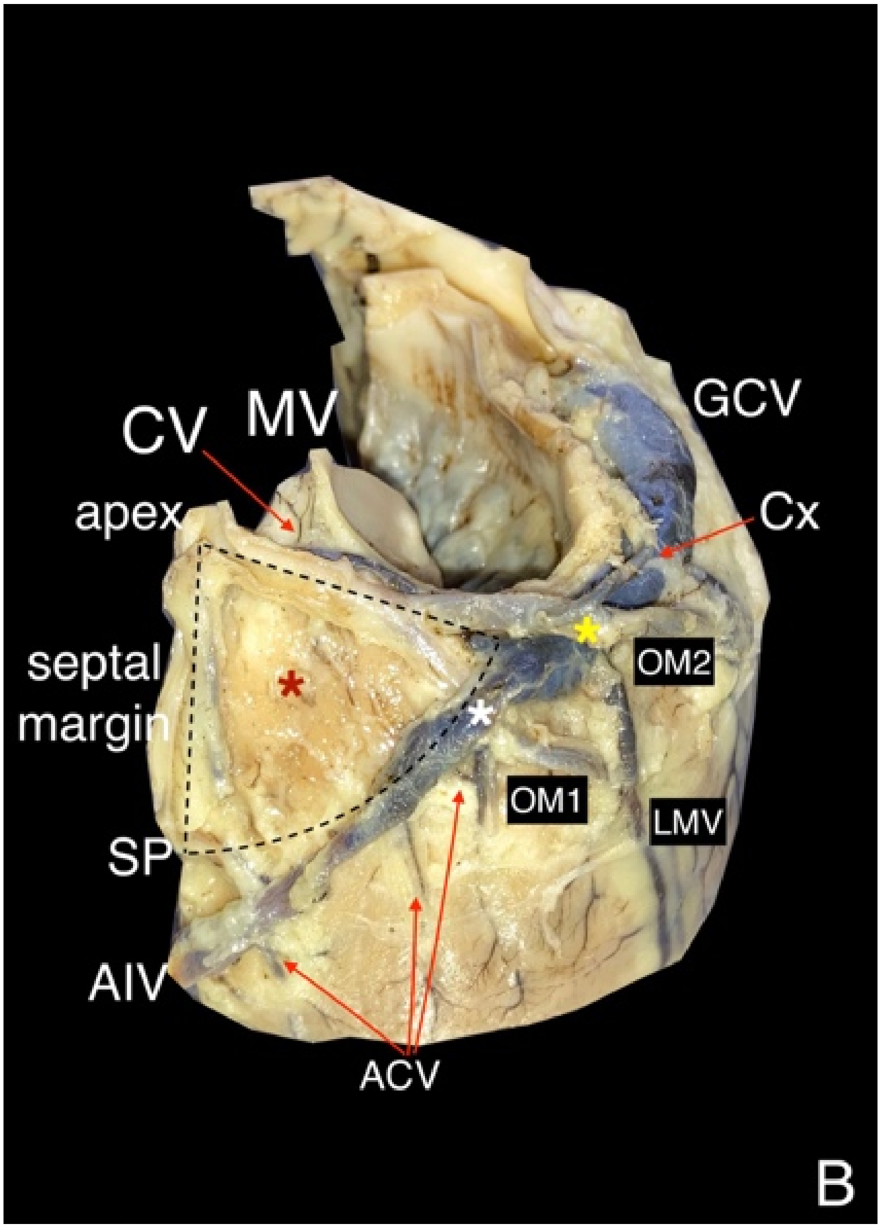
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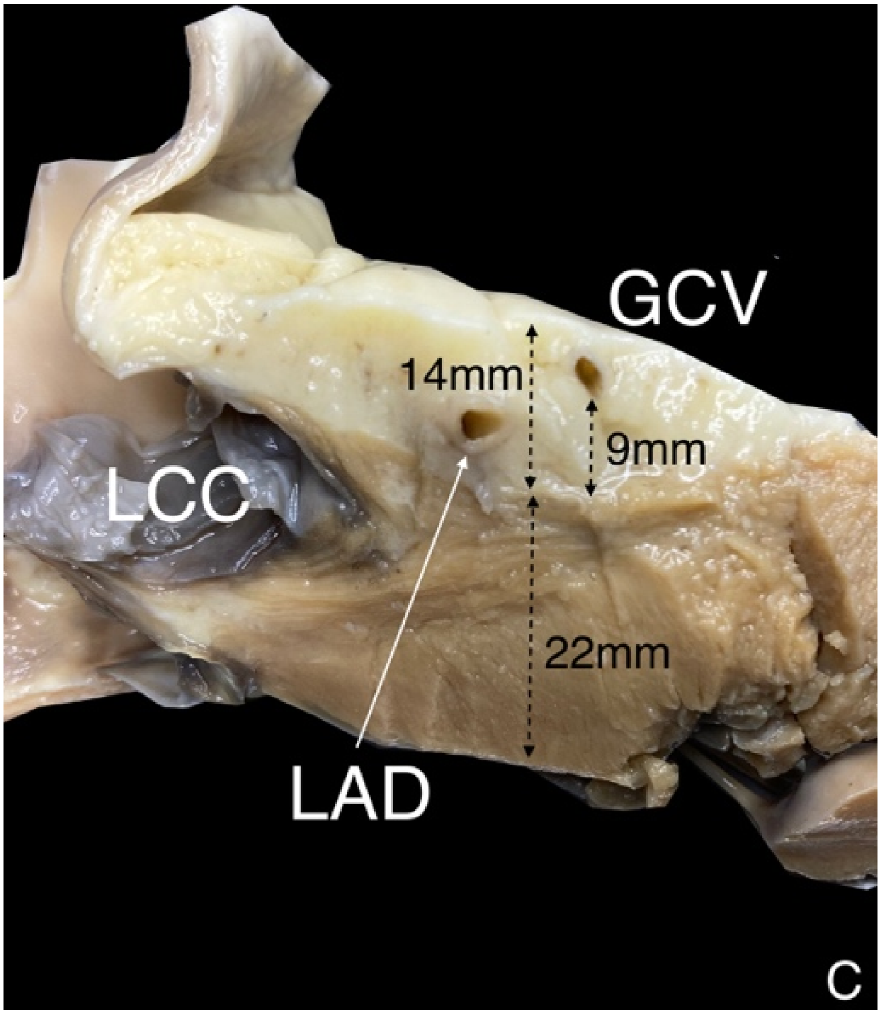


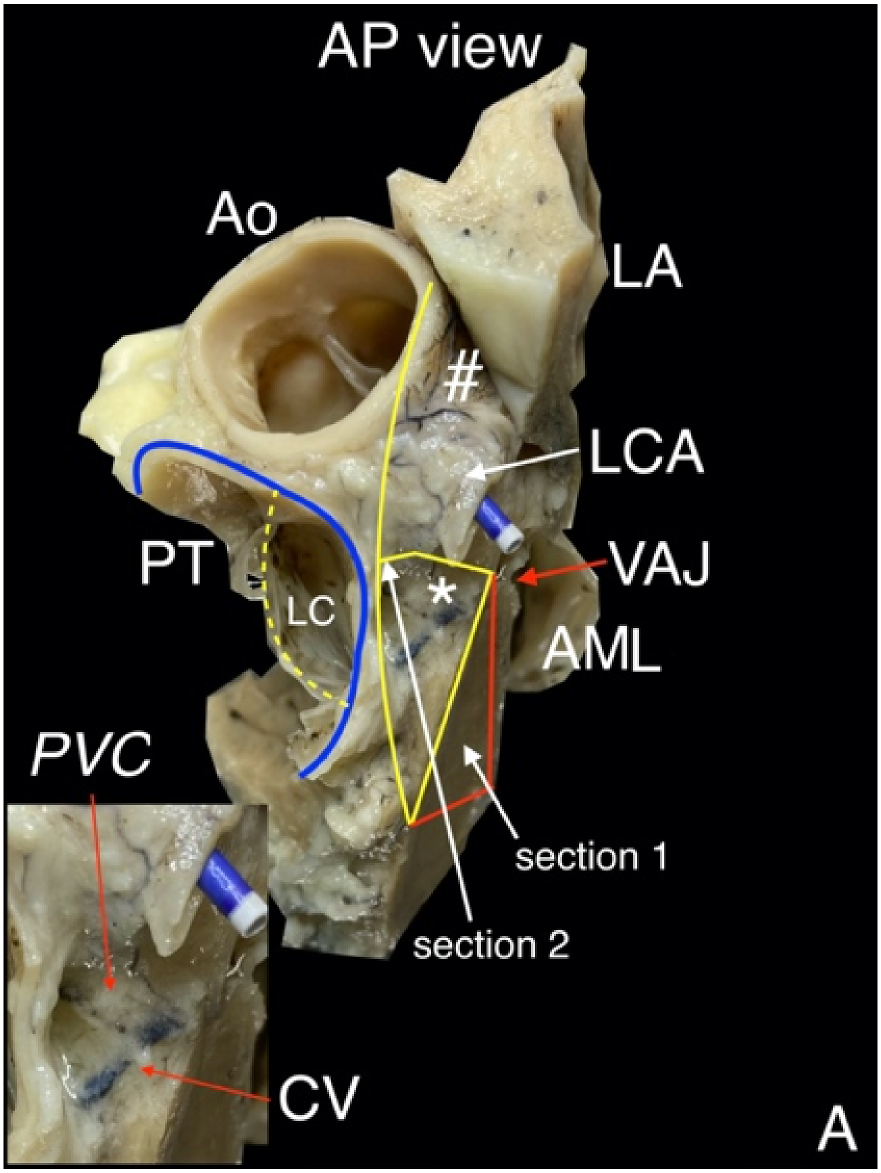
Figure 2. A – section in the septal margin with LVS aspect, close to VAJ the depression above is the left sinus of Valsalva and conus vein (CV) trespassing in front of it. B – LVS after EAT removal red Asterix, white Asterix GVC over OM1, yellow Asterix GCV below to the OM2, behind Cx conus vein marked; C – dissection in L-R interleaflet trigon – thickness of LV and EAT was measured; **Abbreviations:**LVS = left ventricular summit; LAD = left anterior descending artery; LCA – left coronary artery; Cx = circumflex branch of left coronary artery; GCV = great cardiac vein; AIV = anterior interventricular vein; SP= septal perforator; OM = obtuse marginal; LAA = left atrial appendage; MV – mitral valve, VAJ – ventriculo aortic junction, CS – coronary sinus, RA – right atrium, LA – left atrium, AML – anterior mitral leaflet, LCC – left coronary cusp, CV – conus vein, LSPV – left superior pulmonary vein, LIPV – left inferior pulmonary vein, ACV – anterior cardiac veins.

Interior aspect

Inside the LVS, the presence of the great cardiac vein is almost inevitable. However, LVS may come without a coronary sinus tributary when the short distance between bifurcation to septal perforator excludes vessels from the defined LVS area. In anatomical terminology, great cardiac vein begins at the heart's apex and ascends along the anterior longitudinal groove to the base of the heart, while in cardiology and radiology, the initial segment from the apex of the left ventricle to the LVS is named the anterior interventricular vein[7]. In definition, the anterior interventricular vein originates at the lower or middle third of the anterior interventricular groove, follows the groove adjacent to the left anterior descending artery, and angulates laterally toward the heart's base to form the great cardiac vein [2]. The coronary venous system lying in the LVS region is sunken in the epicardial adipose tissue, and distance to the left ventricular surface may be wary (Figure 2c). This distance might impact ventricular potential amplitude recorded from the great cardiac vein if the epicardial adipose tissue is significantly thick. Mostly, the venous system intersects coronary vessels deeply [Figure 4A], while in $\frac{1}{4}$ of the specimens, it does so superficially. The relationships between the great cardiac vein – anterior interventricular vein and the coronary arteries vary between patients [6]. The point of transition between the anterior interventricular vein and the great cardiac vein lies inside the LVS and arguably a significant source of epicardial idiopathic ventricular arrhythmias [9].The coronary venous system plays an essential role in the LVS division into the superior and inferior aspects. The superior aspect of the LVS is named an inaccessible area; nevertheless, it is recognizable also as the triangle of Brocq and Mouchet [18]. The difference in terminology is that the featured LVS base starts from the first dominant septal perforator while trigon of Brocq and Mouchet when the anterior interventricular vein crosses the anterior interventricular groove. Brocq and Mouchet trigon have five main variations dependent on vessel crossings and relations in heart groves [18]. The inaccessible area is almost triangular, closed at the bottom by the venous system. In some LVS, the superior aspect may dominate in size over the accessible area (figure 1A, B). The inaccessible area contents include the presence of proximal branches from coronary vessels, small veins, and a thick layer of epicardial adipose tissue covered by LAA and pulmonary trunk. Between the anterior interventricular vein / great cardiac vein line and arcuate line, the accessible part of the LVS is present. Mostly irregular in shape with the continuation of coronary vessels originated from the inaccessible area and anterior coronary veins draining into the coronary venous system. The density of coronary branches is significantly lower, as well as epicardial adipose tissue. Often uncovered by the LAA with epicardial approach possibility.

Septal summit/septal aspect of the LVS

The septal summit is the most superior and rightward part of the left ventricle, which starts from the septal margin toward the pulmonary trunk, extending from the ventriculo-aortic junction [figure 1A, 3] down to the first dominant septal perforator. The neighboring structures are the right-left interleaflet trigon from the top, the left pulmonary sinus from the right aspect, and the anterior interventricular groove's content from left. Above the apex of the LVS under the left coronary artery toward the left side, the septal summit corresponds with aortomitral continuity. What is worth emphasizing, the septal summit is in the central aspect of parasternal long axis view in transthoracic heart ultrasound [22]. Inside the septal summit, the conus vein can be present [figure 3A] and posterior veins of the cone. In the presented figure, the conus vein drained into the great cardiac vein and the right atrium, surrounding the pulmonary trunk, via the small cardiac vein, creating the large horizontally orientated venous circle in the coronary sulcus that embraces the entire heart.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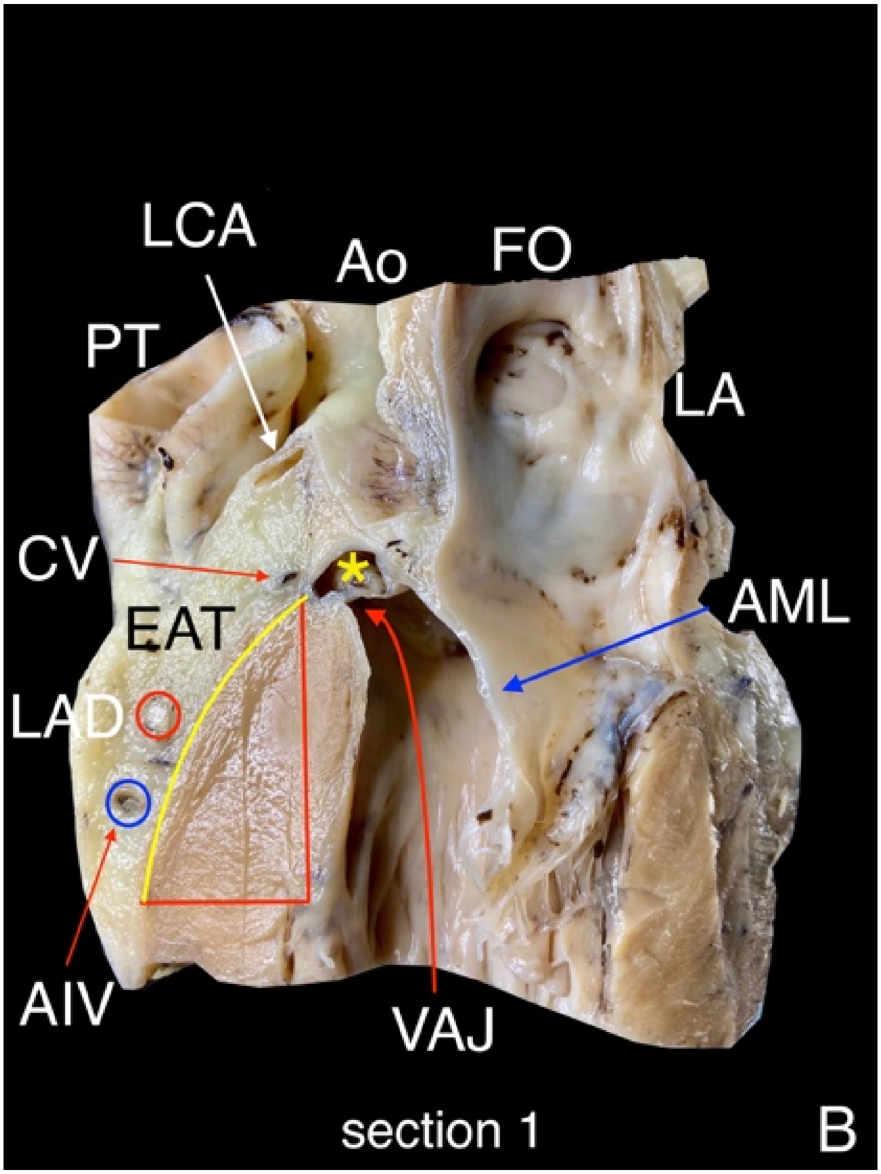
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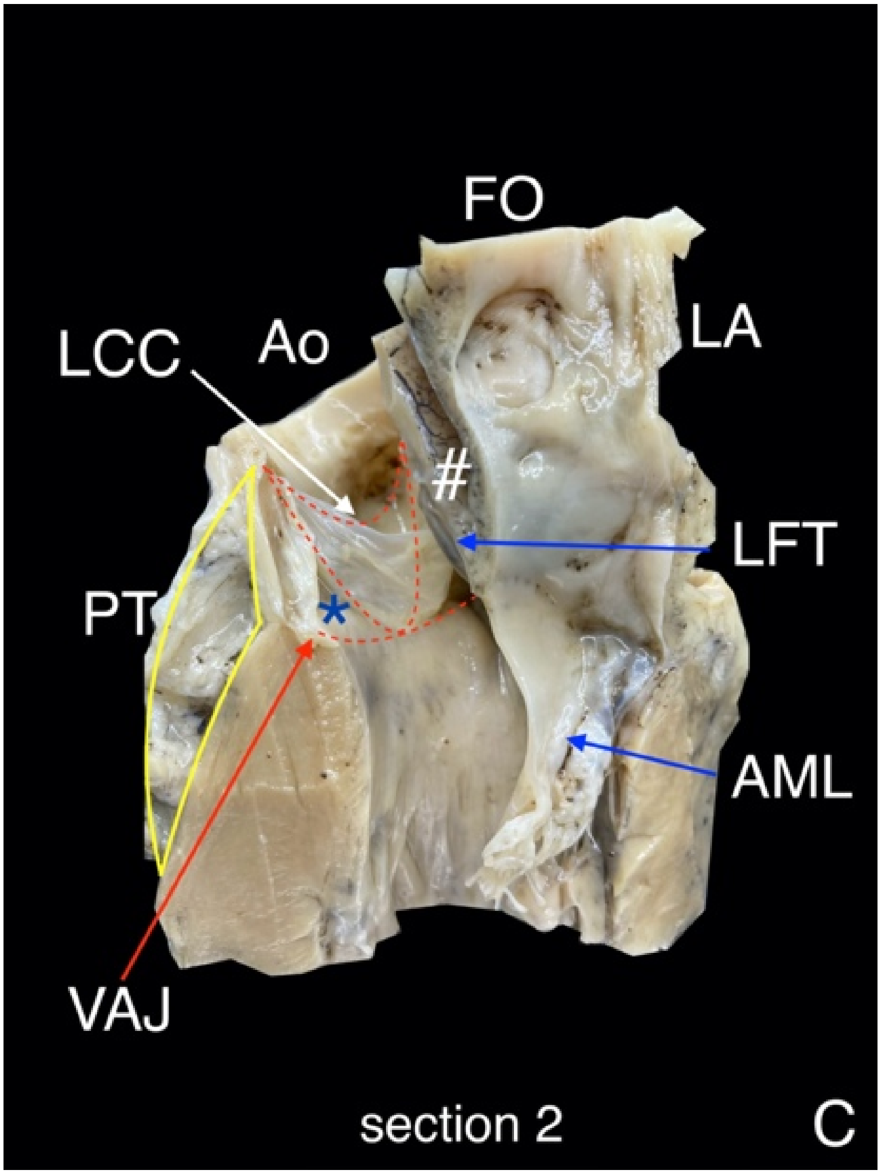


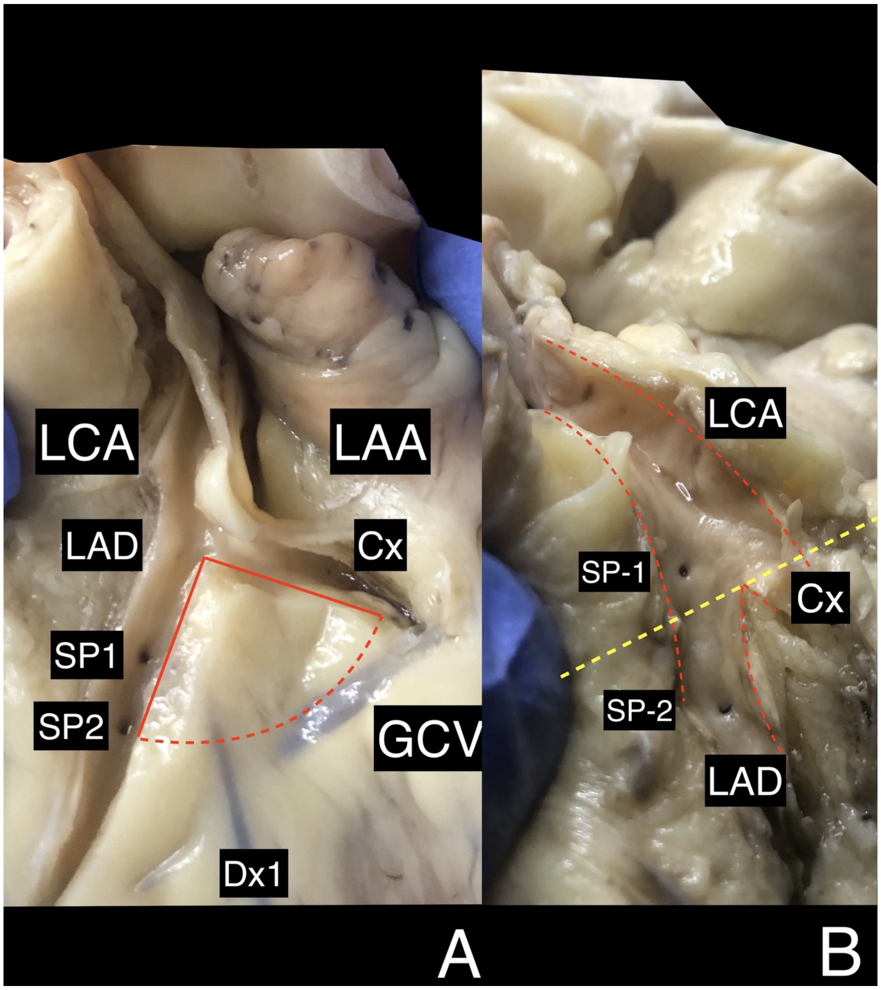
Figure 3 A – block of heart with septal margin of the heart, B – section 1; cut in the anterior interventricular groove, C – section 2; cut on the lateral aspect of the septal summit with the opening of the left coronary cusp; **Abbreviations:** Ao – Aorta, PT – pulmonary trunk, LC left cusp of the pulmonic valve, AML – anterior mitral leaflet, VAJ – ventriculo – aortic junction, LCA – left coronary artery, LA – left atrium, FO – foramen ovale, AIV – anterior interventricular vein, LAD – left anterior descending, LCC – left coronary cusp (red lines presents virtual LCC), LFT – left fibrous trigon, EAT – epicardial adipose tissue, CV – conus vein, *PVC*– the posterior vein of conus; white Asterix, septal summit, yellow asterisk, left sinus of Valsalva, blue asterisk – left-right interleaflet trigon, hashtag – sinus transversus pericardii.

LVS nourishment and innervation.

LVS is receiving the arterial blood from perforating arteries exiting from the left coronary artery branches' proximal segments. The venous collection drains into the coronary sinus (via anterior coronary veins into the interventricular vein - the great cardiac vein) from the lower aspect of LVS and noncoronary sinus via tributaries from the apical aspect and right side of LVS [19]. The left or right superior septal veins drain the superior third of the interventricular septum (ventricular outflow tracts). The left superior septal vein, the longest and largest intramural venous channel, can reach 2–3 mm in diameter [7] and can be used in interventional procedures. The venous drainage from the septal summit is most commonly into the right atrium via the intramural sinus [21], also known as veins of Vieussens, including the veins which drain the adipose tissue covering the conus arteriosus [19]. An important fact is that this region is abundant in venous anastomoses with the axillary orientated circle embracing the entire heart, consisting of the coronary sinus – great cardiac vein – small cardiac vein via conus vein, and further intercommunicating veins (Figure 2B, 3A) [7]. The epicardial region of LVS is covered by the fibers of intrinsic cardiac nervous autonomic system[27] gathering nearly 6% of all ganglionated plexuses of the heart [25]. These plexuses are embedded in the epicardial adipose tissue. The first portion of left coronary ganglionated subplexus with preganglionated nerves is densely distributed nearby pulmonary trunk and ascending aorta in septal summit region. Post-ganglionated nerves extended into ventral, lateral and in part dorsal walls of the left ventricle. Moreover, thin short postganglionated nerves proceed on the interior surface of the left auricle along the atrial branches of the circumflex branch of left coronary artery (Figure 4E) [25]. Subendocardially Purkinje network from the left bundle branch's anterior division, most likely, provide the activation into the LVS region. Anterior division of left bundle branch proceed toward the base of the anterior papillary muscles of the mitral valve. It is formed of many fine strands coursing anteriorly to the free wall [24] thus it is most probable that the LVS region is supported by this segment, however both networks from anterior and posterior divisions of left bundle branch are widely interconnected [26].

Defining the size of LVS

The size of the LVS may vary and does not correlate with BMI, sex, or age. The distance from left coronary artery bifurcation to the first septal perforator (length of the LVS septal margin) [figure 4] determines LVS size. A calculation using a Yamada equation identifies the area with a high correlation to real LVS size [4]. The biggest challenge in area measurement is depicting the proper septal perforator. Many septal perforators can be found in the proximal aspect of the left anterior descending artery (from 1 to 3 on the first 25 mm distance). The first anterior septal branch is usually the most extensive (4-6cm length) and provides the most important collateral channels. However, only 30% of normal angiograms demonstrate a large (1.5 mm in diameter or larger) first septal perforator distally arborizing into at least four branches. 28% of cases find that the first perforator is a small artery, while a further 24% demonstrate two or three comparable in size arteries; in the last 18% of the hearts, the septal perforator diffuse into multiple small septal arteries [10] [Figure 4 A and B].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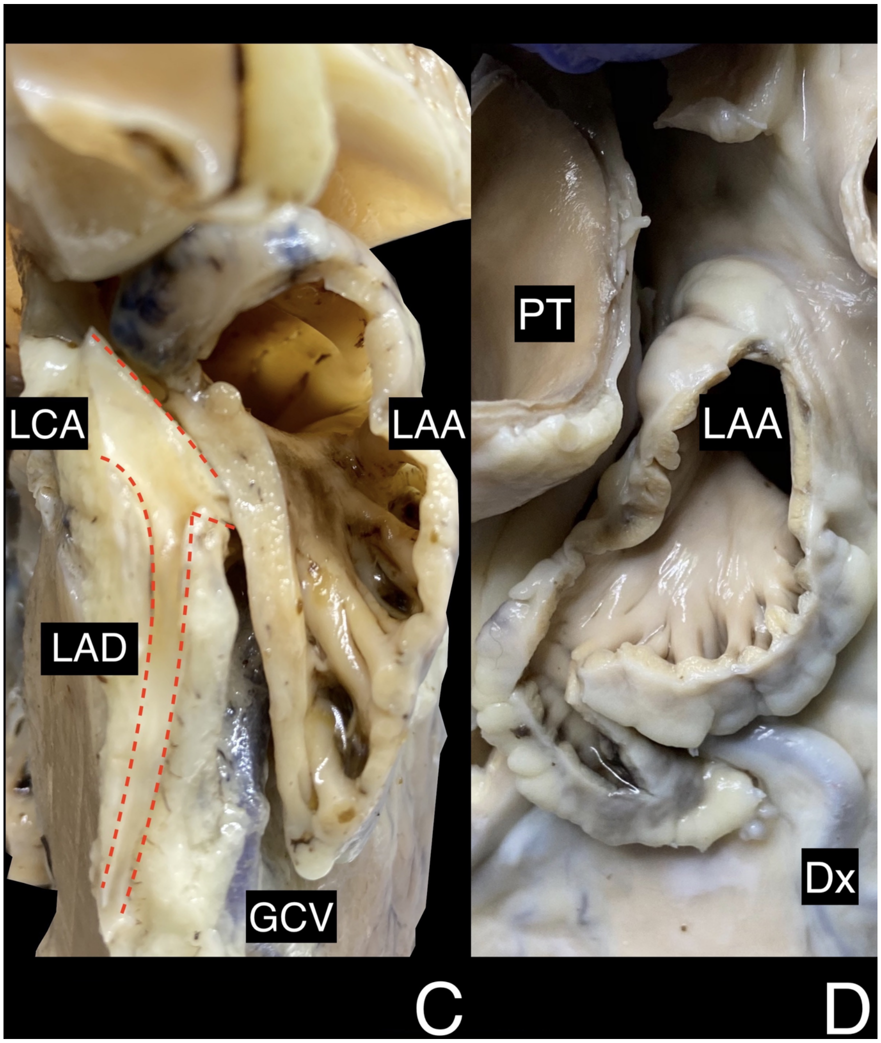
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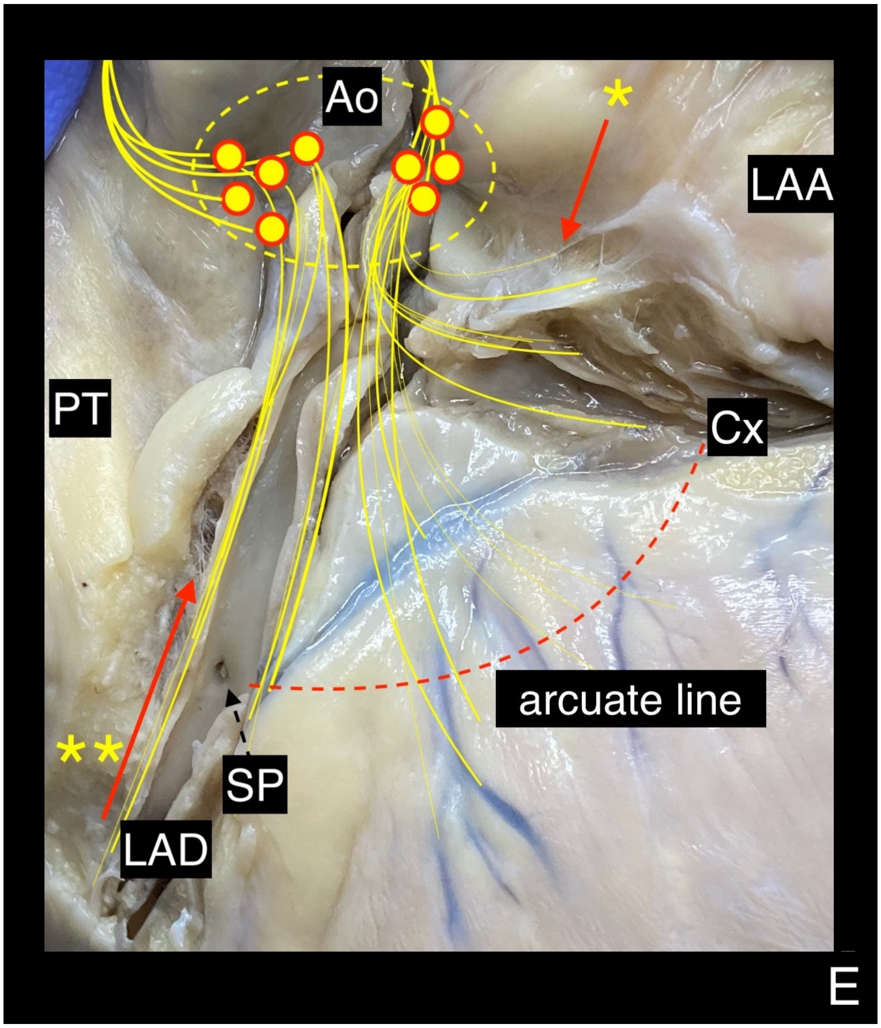


Figure 4 (A) Septal perforators (SP) in LAD, SP1 – smaller and SP2 – bigger; the area of LVS has only an inaccessible area; (B) – SP in proximal distance, SP – 1 in the LCA trunk, SP – 2 – dominant define very small LVS area; (C) – the presence of open LAA over LVS via the thickness of LAA and EAT; (D) the floor of LAA over LVS; (E) schematic distribution of left coronary subganglion with postganglionic autonomic fibers, yellow asterix- nerve fiber conecting with surface of the left auricle along the atrial branches of the circumflex left coronary artery; double yellow asterix – fibers from left coronary cardiac nerve. **Abbreviations:** LCA – left coronary artery, LAD – left anterior descending, SP – septal perforator, Cx – circumflex branch, GCV – great cardiac vein, Dx – diagonal branch, EAT – epicardial adipose tissue,

The LVS size definition should include presented above discrepancies. If in the proximal aspect of left anterior descending artery, there is a discovery of only one septal perforator, the size is indisputable, while if there are more perforators, the LVS definition should take the largest diameter (Figure 4A). There is another reason for choosing the most dominant perforator that relates to available imaging methods. The septal perforator imaging in cardiac computed tomography angiography usually can visualize a vessel larger than 1 mm in diameter. Smaller vessels visible in the macroscopic dissection might be unnoticed in clinical assessment.

LVS accessibility

Access to the LVS is necessary when the ventricular arrhythmia source localization is in this particular area. Because the LVS is an epicardial region, the approach to the LVS may be indirect or direct. The indirect method uses the adjacent structures to get the closeness relation to the earliest activation point of exiting the arrhythmia source. These points ware defined as the vertices of "Bermuda triangle." [23] because of a lack of closeness. The nearest relation to the LVS apex or septal aspect of the LVS is the left coronary cusp of the aortic valve or right-left inter leaflet triangle [2,20]. The right margin approach is possible to perform from the right coronary cusp of the pulmonic valve in superior aspect, pulmonary artery, pulmonary trunk, or RVOT in inferior aspect if anatomy allies. The left margin is accessible from LAA or great cardiac vein [9]. A mid aspect of the LVS is attainable from the venous system great cardiac vein, anterior interventricular vein, and septal venous perforators, or recently proposed LAA, which covered nearly 75% of the LVS region [4] (figure 4C). The access from the endocardial region toward LVS is impossible because of the thickness of the heart muscle. Only the subvalvular aspect of the LV endocardium is thin enough to process the energy to the LVS [13]. The direct approach to the LVS provides access through the pericardial sac. This access also has a limitation - the only reachable part of LVS is an accessible area. The lower part of LVS between arcuate line and great cardiac vein / anterior interventricular vein has less epicardial adipose tissue and less coronary vessel density. The superior portion of LVS between apex and the great cardiac vein / anterior interventricular vein is dangerous for pericardial penetration. It increases the risk of major and minor complications, such as intrapericardial bleeding, coronary artery stenosis, delayed tamponade, and incidental right ventricle puncture [12]. Without coronary angiography before the procedure, mapping or ablating the LVS region may be hazardous, and thus it is a recommendation before the procedure [14].

Ablation in LVS region

Nearly 15% of ventricular arrhythmias from the left ventricle has a source over the epicardial surface of LV [3]. The most common ECG template for LVS arrhythmias is V2 pattern break qrs [15]. The ablation of ventricular arrhythmias from the LVS is challenging and requires various approaches. Delivery of enough RF energy to the arrhythmia source avoiding coronary artery damage may be a challenge [16]. Another pattern outflow tract VA is with abrupt R-wave transition in V3 with its source in the septal margin of the LVS. Additionally, there is proof that shows that the right-left interleaflet trigon is effective in reaching the arrhythmia source (figure 3C blue asterisk) [20]. Access over the LVS region via coronary sinus – great cardiac vein may be challenging because of the complex anatomy of the cardiac venous system, likewise the variable array inside epicardial adipose tissue of great cardiac vein (Figure 2C) for ventricular arrhythmias potential collections.

Conclusions

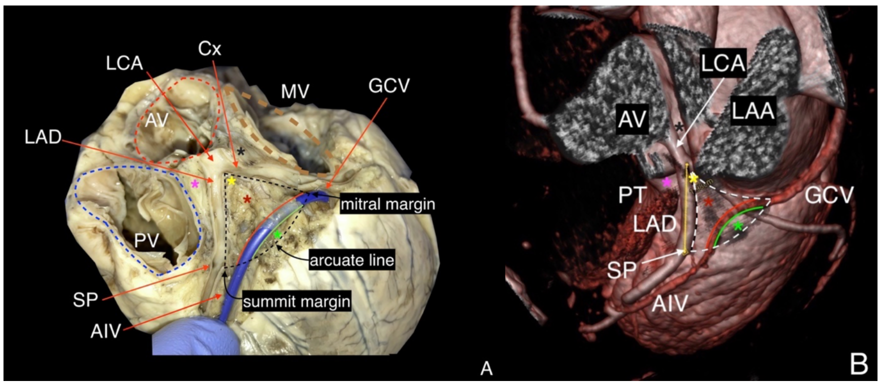
Providing systematic and comprehensive anatomical terminology in the LVS region may facilitate the exchanging of information among anatomists and electrophysiologists, increasing knowledge over this heart region. We found that the most dominant septal perforator should represent the LVS definition, not the first septal perforator. LAA may be a vantage point for better ventricular arrhythmia source identification.

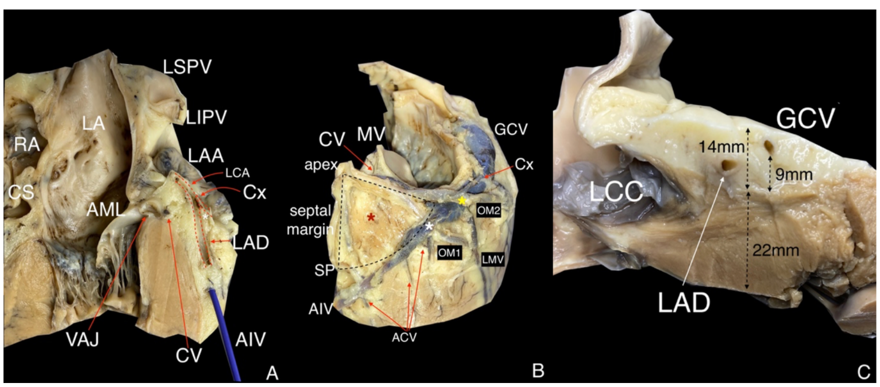
References

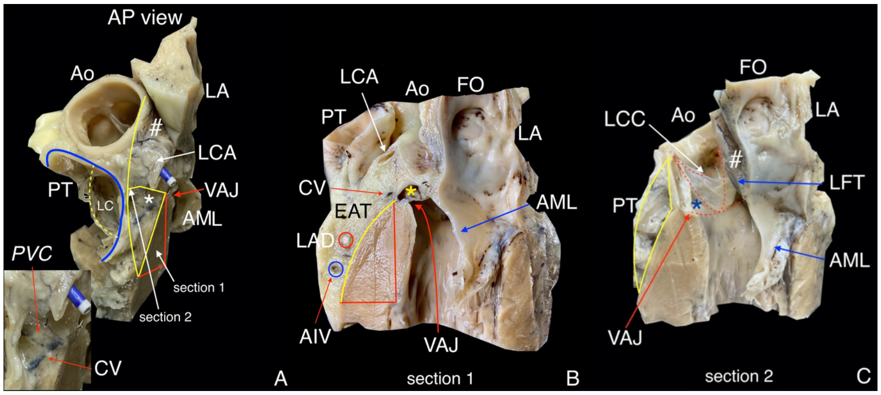
1. Kumagai K. Idiopathic ventricular arrhythmias arising from the left ventricular outflow tract: tips and tricks. J Arrhythm. 2014;30(4):211–21.
2. Enriquez, A., Malavassi, F., Saenz, L. C., Supple, G., Santangeli, P., Marchlinski, F. E., & Garcia, F. C. (2017). How to map and ablate left ventricular summit arrhythmias. *Heart Rhythm* ,*14* (1), 141–148.
3. Yamada, T., McElderry, H. T., Doppalapudi, H., Okada, T., Murakami, Y., Yoshida, Y., ... Kay, G. N. (2010). Idiopathic ventricular arrhythmias originating from the left ventricular summit anatomic concepts relevant to ablation. *Circulation: Arrhythmia and Electrophysiology* , *3* (6), 616–623.
4. Kuniewicz M, Krupiński M, Gosnell M, et al. Applicability of computed tomography preoperative assessment of the LAA in LV summit ablations [published online ahead of print, 2020 Jul 14]. *J Interv Card Electrophysiol* . 2020;10.1007/s10840-020-00817-8.

5. McAlpine WA. Heart and Coronary Arteries. New York, NY: Springer-Verlag, 1975.
6. Ishizawa, A., Fumon, M., Zhou, M., Suzuki, R., & Abe, H. (2008). Intersection patterns of human coronary veins and arteries.*Anatomical Science International* , *83* (1), 26–30.
7. von Ludinghausen M. The venous drainage of the human myocardium. Adv Anat Ebryol Cell Biol 2003;168: I–VIII, 1–104
8. Whiteman, S., Saker, E., Courant, V., Salandy, S., Gielecki, J., Zurada, A., & Loukas, M. (2019). Translational Research in Anatomy An anatomical review of the left atrium. *Translational Research in Anatomy* , *17* (September), 100052.
9. Obel, O. A., Avila, A., Neuzil, P., Saad, E. B., Ruskin, J. N., & Reddy, V. Y. (2006). *Ablation of Left Ventricular Epicardial Outflow Tract Tachycardia from the Distal Great Cardiac Vein* . Journal of the American College of Cardiology, *48* (9), 6–10.
10. Topaz, O., DiSciascio, G., & Vetrovec, G. W. (1992). Septal perforator arteries: From angiographic-morphologic characteristics to related revascularization options. *American Heart Journal* ,*124* (3), 810–815.
11. Michałowska IM, Hryniewiecki T, Kwiatek P, Stokłosa P, Swoboda-Rydz U, Szymański P. Coronary Artery Variants and Anomalies in Patients With Bicuspid Aortic Valve. *J Thorac Imaging* . 2016;31(3):156-162.
12. Sacher F, Roberts-Thomson K, Maury P, et al. Epicardial ventricular tachycardia ablation a multicenter safety study. J Am Coll Cardiol 2010;55: 2366–2372.
13. Santangeli P, Marchlinski FE, Zado ES, et al. Percutaneous epicardial ablation of ventricular arrhythmias arising from the left ventricular summit: outcomes and electrocardiogram correlates of success. Circ Arrhythm Electrophysiol 2015;8: 337–343.
14. Yamada T, McElderry HT, Doppalapudi H, et al. Idiopathic ventricular arrhythmias originating from the aortic root prevalence, electrocardiographic and electrophysiologic characteristics, and results of radiofrequency catheter ablation. J Am Coll Cardiol 2008;52:139–147
15. Daniels DV: Idiopathic epicardial left ventricular tachycardia originating remote from the sinus of Valsalva: Electrophysiological characteristics, catheter ablation, and identification from the 12-lead electrocardiogram. Circulation 2006;113:1659-1666
16. Hayashi, T., Santangeli, P., Pathak, R. K., Muser, D., Liang, J. J., Castro, S. A., ... Marchlinski, F. E. (2017). Outcomes of Catheter Ablation of Idiopathic Outflow Tract Ventricular Arrhythmias With an R Wave Pattern Break in Lead V2: A Distinct Clinical Entity.*Journal of Cardiovascular Electrophysiology* , *28* (5), 504–514.
17. Pejkovic B, Bogdanovic D. The great cardiac vein. *Surg Radiol Anat* . 1992;14(1):23-28.
18. Andrade, Filipe & Ribeiro, D.C. & Babinski, Marcio & Cisne de Paula, Rafael & Góes, M.L. (2010). Triangle of Brocq and Mouchet: Anatomical study in Brazilian cadavers and clinical implications. Journal of Morphological Sciences. 27. 127-129.
19. Saremi F, Muresian H, Sánchez-Quintana D. Coronary veins: comprehensive CT-anatomic classification and review of variants and clinical implications. *Radiographics* . 2012;32(1): E1-E32.
20. Liao H, Wei W, Tanager KS, et al. Left ventricular summit arrhythmias with an abrupt V_3 transition: Anatomy of the aortic interleaflet triangle vantage point [published online ahead of print, 2020 Jul 21]. *Heart Rhythm* . 2020; S1547-5271(20)30677-9.
21. Ortale JR, Marquez CQ. Anatomy of the intramural venous sinuses of the right atrium and their tributaries. *Surg Radiol Anat* . 1998;20(1):23-29.
22. Islam Aly, Asad Rizvi, Wallisa Roberts, Shehzad Khalid, Mohammad W. Kassem, Sonja Salandy, Maira du Plessis, R. Shane Tubbs, Marios Loukas, Cardiac ultrasound: An Anatomical and Clinical Review, Translational Research in Anatomy, 2020, 100083, ISSN 2214-854X,
23. Altmann, D. R., Knecht, S., Sticherling, C., Ammann, P., Osswald, S., & Kühne, M. *Ventricular tachycardia originating from the " Bermuda Triangle ."* Cardiovascular Medicine 2013;16(7–8):208–210
24. Spach MS, Huang S, Armstrong SI, Canent Jr R. Demonstration of peripheral conduction system in human hearts. Circulation 1963;28:333–8.
25. Pauza DH, Skripka V, Pauziene N, Stropus R. Morphology, distribution, and variability of the epicar-

diac neural ganglionated subplexuses in the human heart. Anat Rec. 2000 Aug 1;259(4):353-82.
26. Elizari MV. The normal variants in the left bundle branch system. J Electrocardiol. 2017 Jul-Aug;50(4):389-399. Epub 2017 Mar 14. PMID: 28341304.
27. Wink J, van Delft R, Notenboom RGE, Wouters PF, DeRuiter MC, Plevier JWM, Jongbloed MRM. Human adult cardiac autonomic innervation: Controversies in anatomical knowledge and relevance for cardiac neuromodulation. Auton Neurosci. 2020 Sep;227:102674. doi: 10.1016/j.autneu.2020.102674. Epub 2020 May 16. PMID: 32497872.
28. Janes, R.D., Brandys, J.C., Hopkins, D.A., Johnstone, D.E., Murphy, D.A., Armour, J.A., 1986. Anatomy of human extrinsic cardiac nerves and ganglia. Am. J. Cardiol. 57, 299–309.
29. Kosiński A, Grzybiak M, Skwarek M, Hreczecha J. Distribution of muscular bridges in the adult human heart. Folia Morphol (Warsz). 2004 Nov;63(4):491-8. PMID: 15712149.



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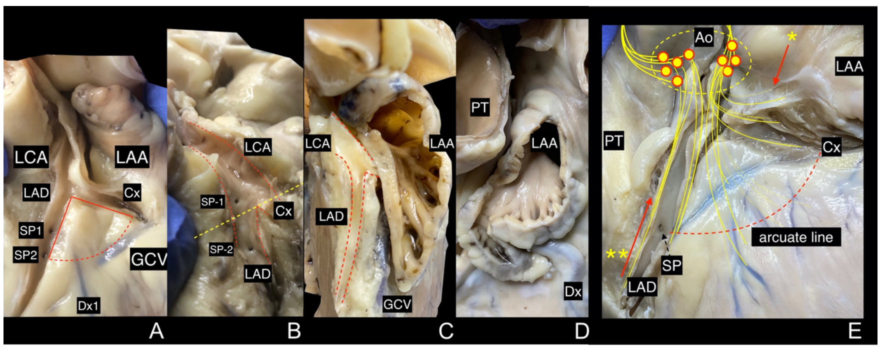
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