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·综　　述·

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［**摘要**］ 随着心脏电生理检查、导管消融和植入器械等技术的开展日益增多，电生理相关心房解剖愈发受到心血管医师的关注。随着心脏 CT 技术的不断进展，其逐渐被用于心房结构个体化解析，为临床诊治提供更详细的依据。本文围绕左心房、右心房、房间隔及与心房关系密切的冠状静脉窦等电生理结构的心脏 CT 解析相关研究作一综述，以期提高医师和科研工作者对心房相关解剖与新成像方法的认识，从而助力心血管疾病的精准诊疗。

［**关键词**］ 心房；电生理；解剖；CT；房间隔；Koch's 三角；心律失常
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Research progress of CT imaging of cardiac electrophysiological anatomy

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［**Abstract**］ With the extensive applications of cardiac electrophysiological examination, catheter ablation and implantation technology, the atrial anatomy related to electrophysiology has attracted wide attention from cardiovascular specialists. Moreover, with the continuous progress of cardiac CT technology, it gradually be used to conduct a more detailed individualized analysis for atrial structure, providing more detailed and data for clinic. This article summarize current researches regarding the electrophysiological structure of left and right atriums, atrial septum and coronary sinus related to atrium based on up-to-date cardiac CT technology. As a result, it will help doctors and researchers improve the understanding of atrium-related anatomy and new imaging technology, and subsequently help with precise diagnosis and treatment of cardiovascular diseases.

［**Key Words**］ atrium; electrophysiology; anatomy; CT; atrial septum; koch's triangle; arrhythmias

心脏电生理检查和导管消融技术在临床工作中的应用越来越广泛，心脏电生理疾病也越来越受到心血管病医师的重视。心脏电生理疾病和相关诊疗技术与心脏结构及解剖密切相关。心房解剖更是心脏电生理检查、心律失常导管消融及起搏器植入等多种操作和手术的重要基础。因此，加深对心房解剖结构的认识，能够帮助术者理解疾病发生机制、精准制定手术策略、减少操作相关并发症。

多层螺旋 CT 高空间分辨率及时间分辨率已被临床广泛认可。作为一项无创检查技术，多层螺旋能 CT 对左心房、左心耳及左心室结构和功能扫描、测量及评估，对左心耳血栓的检出灵敏度高于心脏 MRI 检查[1]，且三维容积再现、最大密度投影、多平面重建及仿真内窥镜等后处理技术，能将左心房、左心耳、肺静脉之间的解剖结构进行再现，更方便观察这些结构的位置及形态[2]，从而为临床医师提供更详细的心脏解剖结构信息。这些

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信息不仅能够深化电生理工作者对心脏解剖的认识，也有助于个体化治疗方案的制订。

1 右心房及毗邻结构

1.1 *右心房* 右心房由前侧的心房体部与后侧的静脉窦部组成，两者由界嵴分隔开。右心耳由原始右心房发育而成，位于右房室沟前上方，表面较平坦，内壁存在相互交叉的梳状肌[3-4]。女性右心耳基底部长径、短径及面积均大于男性，且右心耳容积与心脏发育有关[5]。窦房结为窦性心律的起搏点，位于上腔静脉与右心耳之间，故右心耳起搏能保证正常的激动顺序，为起搏器常用心房电极植入点。由于右心耳解剖变异较多，起搏器导线定位及走行时可能遇到复杂情况，而通过对右心耳形态进行3D重建，可能有助于解决该问题，进而防止电极脱位[6]。右心耳是心房颤动血栓形成部位之一[7]，也是部分房性心动过速的消融部位[8]。

界嵴位于右心房侧壁，是上腔静脉口前方至下腔静脉口前方的肌性隆起，与欧氏嵴相连续。界嵴将右心房分为由原始静脉窦形成的光滑部和由原始心房部形成的小梁肌部[9]，这两部分存在组织学差异使界嵴成为心脏电传导系统的天然屏障。李嫣等[10]通过64层螺旋CT三维重组，得出界嵴长度为17.7～46.3 mm，平均（28.3±5.2）mm，左上下肺静脉交接水平界嵴宽度0.8～10.2 mm，平均（4.8±2.0）mm。电生理医师可以通过将电解剖标测图像与CT三维重组图像相结合，观察导管在腔内嵴部的贴靠情况及导管的位置和深度，减少并发症。界嵴的肌细胞延纵轴整齐排列，其周围的肌细胞倾斜排列，使界嵴成为房性心动过速的好发点[11]。三尖瓣环部为房扑信号传导的前方障碍，界嵴与欧氏嵴为房扑后方障碍[12]。不同人群界嵴的形态和长度差异较大，如房间隔脂肪瘤性肥大的患者，界嵴通常大于正常。Mizumaki等[13]研究发现，肥厚的界嵴与房扑发生相关。因此，对界嵴大小和形态改变认识的加深，有助于降低术中解剖结构变异相关不良事件的发生率。

三尖瓣峡部位于三尖瓣与下腔静脉之间，分为靠近间隔部分、中间部分、下侧部，分别长（16.2±3.2）mm、（19.5±4.4）mm、（24.8±4.8）mm[14]，是峡部依赖型房扑常规消融靶点。三尖瓣峡部深度与长度变异性较大。Okumura等[15]利用心腔内超声发现，合并典型房扑患者的三尖瓣峡部长度明显长于无房扑患者。三尖瓣峡部的形态、大小变化可影响导管射频消融手术，形态的变异使射频消融更加困难。术前通过CT检查了解不同部位三尖瓣峡部的形态，有助于电生理医师选择适宜的区域进行消融[14]。

右心房静脉系统可分为上腔静脉与下腔静脉，上腔静脉位于上纵隔右前部，由左右头臂静脉汇合而成，携带约全身1/3的静脉血。上、下腔静脉肌袖参与部分房颤的发生，下腔静脉前缘的欧氏嵴参与典型房扑的发生。上腔静脉电隔离有利于提高房颤射频消融成功率，但存在损伤膈神经及窦房结等风险[16]。上腔静脉与下腔静脉横断面的左右径常大于前后径，内径随呼吸、体位、心动周期及血容量变化[17]。上腔静脉变异包括永存左上腔、永存左上腔伴右上腔静脉缺如、双上腔静脉等[18-19]。其中，永存左上腔与传导阻滞、窦房结功能障碍、房颤、室颤等心律失常有关[20-21]；左上腔在CT上主要表现为主动脉弓左侧边界清楚结节影，连续出现至少3个平面，可伴冠状窦增粗[22]。下腔静脉解剖变异包括高位分叉、分支、缺如、左位下腔静脉等，常合并其他脏器属支变异。其中，左位下腔静脉的发生率约为0.1%；该类人群腹部CT上肾静脉水平以下缺乏右侧下腔静脉，有助于与双下腔静脉畸形相鉴别[23]。上腔静脉和下腔静脉解剖变异一般不引起症状，大多通过CT等影像检查发现，但易被误诊为肿块样病变，导致不正确治疗，因此计划手术治疗时应排查这些异常，以拟定更合适的方案[24]。

Koch's三角是位于右心房房间隔下部的三角区域，上界为中心纤维体、后界为Todaro腱、前界为三尖瓣隔瓣附着缘、后下界为冠状窦口。孙欢等[25]通过分析行心脏CT检查患者的影像数据得出，Koch's三角上部、下部及冠状窦口方向测值分别为57.2°±9.5°、58.2°±9.1°和52.3°±8.4°，三角的上部和下部角度差异无统计学意义，因此可通过冠状窦口角度预测Koch's三角方向。在Koch's三角水平上，部分患者的房室结动脉走行于

靠近冠状窦的心内膜下方；尸检发现，在Koch's三角底部，房室结动脉与心内膜表面的平均距离为（3.5±1.5）mm[26]，这可能为在该部位射频消融时发生房室结动脉损伤的原因。Koch's三角是室上性心动过速"快径"消融的常用靶点。Ong等[27]研究表明，冠状窦开口大小影响Koch's三角的范围，且Koch's三角方向与冠状窦角度存在线性关系[28]，提示了解冠状窦口角度对Koch's三角的定位及相关导管射频消融手术尤为重要。

希氏束位于Koch's三角顶部，为房室结的延续，穿过中心纤维体，走行于室间隔肌性部与右纤维三角之间，分为左右束支走行于室间隔膜部后下缘。左束支走行于无冠窦和右冠窦交界的下方，其分支呈带状外观分布于心内膜下；右束支较为细长，走行于节制索上，是束支折返性心动过速的常见消融靶点。对于房性心动过速患者，可于中心纤维体上部靠近希氏束的位置行射频消融[29]。临床研究[30]发现，希浦系统起搏对房颤伴心衰、心肌病伴左束支传导阻滞等患者具有很好的疗效；在对心室起搏依赖患者中，希浦系统起搏也有助于保持良好的心室同步性。

1.2　*右心房毗邻组织或结构*　膈神经位于后纵隔内，距离上腔静脉（0.3±0.5）mm、右上肺静脉（2.1±0.4）mm[31]。右膈神经距离右上肺静脉最小距离为（2.1±0.4）mm[32]，当射频消融靶点位于右肺静脉时，容易导致右膈神经损伤[33]。左膈神经以相对固定的角度沿心包腔左侧缘向下走行，与左缘静脉及前室间静脉部分重叠，在心脏再同步化治疗（CRT）中易发生膈神经刺激[34]；在复杂房性心律失常射频消融中，若消融靶点靠近左心耳，也会导致左膈神经受损[35]；位于消融靶点5 mm以内的膈神经在消融过程中有更高的损伤风险[36]。膈神经麻痹为冷冻消融最常见的并发症，发生率高达11.2%[37]。多层螺旋CT证实右膈神经血管束贯穿右室心包；虽然无法通过CT直接观察膈神经的具体结构及位置[38]，但可通过其毗邻结构的构象及其周围所包裹的脂肪组织判断其神经的位置[39]。右侧膈神经损伤多于左侧，上支多于下支[40]。损伤引起的膈神经麻痹是心脏[41]、肺[42]、纵隔[43]手术的常见并发症之一，术前通过对膈神经及周围组织的CT三维重建有助于降低膈神经麻痹的发生风险[44]。

房间隔是由卵圆窝瓣膜和卵圆窝前下部分组成的膜性结构，与Koch's三角的顶端相毗邻[9]，最薄弱部位为卵圆窝，为房间隔穿刺最佳位置。CT影像示，房间隔上缘为上腔静脉与右肺静脉的折叠成分，前缘和下缘通过脂肪组织与心室分离，整体位于横心包窦和主动脉根后面，但在房室增大、严重的脊柱后侧凸、右室肥大或主动脉增大时，房间隔平面起源位置会发生改变，导致卵圆窝移位[45]。房间隔形态相关变异可见于房间隔缺损、房间隔动脉瘤、房间隔脂肪瘤等。高端CT有利于观察心内解剖及周围大血管的解剖结构，准确定位房间隔解剖结构及显示房间隔缺损的位置、形态和大小[46]。钱勇等[47]通过320排CT证实，房间隔缺损和卵圆窝未闭是常见房间隔病变。冠状动脉CT血管成像中，房间隔缺损表现为房间隔连续性中断，呈膜孔样缺损，对比剂分流束垂直于房间隔从左心房射向右房；卵圆窝未闭表现为房间隔出现"隧道样"结构，并见对比剂分流束从左心房朝下腔静脉方向射向右房，分流束末端呈现"拐弯"或发散现象。房间隔瘤表现为房间隔囊袋状凸向一侧心房内或在两侧心房间摆动。石佳等[48]发现，房间隔起搏可缩短心房间传导时间、减小心房不应期离散度，增加左右心房收缩同步性。这为房间隔起搏预防房颤发生的理论基础。相比于右心耳起搏，房间隔起搏在预防病态窦房结综合征及房内传导阻滞患者进展为持续性房颤、阵发性房颤方面更占优势[49]。

冠状静脉窦开口于下腔静脉口内上方与右心房室瓣环之间，由心大静脉、心中静脉、心小静脉、后室间静脉等分支静脉汇合而成[50]，在左心房与右心房的电传导过程中起重要作用。正位X线片，冠状静脉窦口位于横膈上2～3 cm，脊柱中线与左缘之间；右前斜位30° X线片时，冠状静脉窦口在横膈上2～3 cm，脊柱左侧外缘2～3 cm。Sun等[51]利用256层螺旋CT发现，冠状静脉窦口上下径大于前后径，进而得出冠状静脉窦口为椭圆形的结论。这对于将导管顺利通过窦口置入冠状静脉非常重要。慢性心力衰竭患者冠状静脉

窦口解剖异常的发生率较高[52]。陈轶等[53]通过多层螺旋CT发现，冠状静脉窦口结构异常包括：（1）闭锁，即冠状静脉通过异常通路回流到右心房、左心房或左右双心房；（2）Thebesian瓣，即Thebesian瓣覆盖冠状静脉窦口大部分甚至全部，部分呈条带状或网状；（3）移位。在CRT中，通常将左室电极通过冠状窦送至冠状静脉分支血管，电极最佳植入位置为心侧静脉、心后静脉或心外侧静脉，在这些位点起搏可改善房室间、双心室间及左心室内收缩同步性。Garcia等[54]术前利用多层螺旋CT对冠状静脉系统进行描述，明显优化了CRT手术方案。Doganay等[55]在CRT术前，利用64层螺旋CT对冠状静脉进行评估，缩短了手术时间，提高了手术成功率。CT可用于评价冠状静脉系统的静脉数量、大小，与周围动脉的关系等，以确定手术的最佳入路与选择导管、电极[56]，且包含CT的多种影像学结合的形式有助于提高CRT治疗心力衰竭的疗效[57]。国外学者研究[58]发现，冠状窦口越大，越容易发生房室结折返性心动过速，该病变"慢径"消融靶点常选择冠状窦上缘5 mm、三尖瓣环侧。因此，冠状窦在左心室起搏、心律失常的消融方面起到重要作用。

2　左心房及毗邻结构

2.1　*肺静脉*　左心房血液来源于肺静脉系统，多层螺旋CT显示右肺静脉开口靠近房间隔，右上肺静脉靠近上腔静脉或右心房，右下肺静脉接近水平方向；左上肺静脉靠近左心耳，左下肺静脉靠近降主动脉[59]。男性肺静脉直径大于女性[60]；房颤患者肺静脉直径大于非房颤患者[61]；持续性房颤患者肺静脉直径大于阵发性房颤患者[62]。上肺静脉开口直径（19～20 mm）大于下肺静脉（16～17 mm）[59]，更易成为房颤起源灶[7]。肺静脉的解剖变异性较大；在异位起搏患者中，36%由肺静脉异常所致[4]，包括独立中肺静脉、肺静脉共干、肺静脉引流入左心房其他结构。对于接受冷冻球囊消融的患者，肺静脉口的解剖形态对球囊封堵效果产生一定影响，如左肺静脉共干开口较大或呈卵圆形时，球囊通常难以完全封堵[63]。术前可通过CT/MRI测量肺静脉开口直径，预测冷冻球囊隔离肺静脉的难易程度和膈神经损伤风险[33]。环肺静脉隔离术后肺静脉狭窄率为1.3%～3.0%[64]，而CT作为环肺静脉隔离术后随访的主要影像学检查手段[65]，有助于及时发现肺静脉狭窄[66]。邸成业等[67]通过左心房-肺静脉CT发现，房颤患者冷冻消融术后30～40 d，左上肺静脉开口短径缩短最多，可能与其后壁偏薄，术后更易发生纤维化及瘢痕有关。非特异性症状出现后，肺静脉狭窄诊断率升高[68-69]。因肺静脉解剖结构较为复杂，常需多层螺旋CT结合三维容积再现、多平面重建、仿真内窥镜等多种后处理技术，才能更好地观察肺静脉形态及测量其直径和长度[2]。但房颤患者心律绝对不齐，且CT扫描质量与患者吸气末期屏气能力及能否耐受β受体阻滞剂（控制心率）有关[70]，因此，有时很难获得高质量图像。

2.2　*左心房*　二尖瓣由半圆形前叶和新月形后叶组成，基底部附着于纤维环。左室乳头肌牵拉是二尖瓣叶开放的保证。健康人二尖瓣腱索厚度为0.4～1.2 mm，二尖瓣环周长约10 cm，二尖瓣面积4～6 cm^2[71]。CT影像可提供二尖瓣形态、功能等信息[72]，其中CT平扫不易区分正常瓣膜与心肌组织，而增强CT可区分高密度的血液及等密度的二尖瓣膜结构，且有助于判断二尖瓣狭窄程度、辨别二尖瓣反流性质及发现术后并发症[73]。但是，对于黏液瘤所致的二尖瓣异常，多层螺旋CT诊断效能不及经食管超声心动图检查（TEE），且无法测量二尖瓣瓣口流速[70]。二尖瓣峡部位于左下肺静脉口下部和二尖瓣环之间的左心房后外壁时，由于该区域横断于心外膜方向走行的左回旋支、心大静脉及冠状静脉窦上[74]，在该区域进行射频消融易损伤冠脉血管，造成左回旋支闭塞[75]。商智杰等[76]研究发现，应用多层螺旋CT可准确评价冠状动、静脉系统的解剖结构及其毗邻结构，术前应用可降低房颤患者术中左回旋支闭塞的风险。

左心房顶部线即在左心房顶部连接左右肺静脉消融环的径线，根据其形态特点可分为隆起型、平坦型及凹陷型[77]，以后两者多见。左心房顶部形态影响射频消融的成功率，如为隆起型时，由于消融电极不易固定，容易发生电极脱落，导致肺静脉隔离不完全。对于房颤患者，尤其是持续性房

颤患者，左心房顶部消融在术后维持窦性心律方面起重要作用[78]，且结合左心房顶部线冷冻球囊消融较单独环肺静脉隔离术改善预后的效果的更好[79]。刘浩等[80]通过分析左心房形态解剖学的CT成像特点发现，房颤组左心房顶部线长度大于非房颤组，但其深度在两组无明显差异。因此，术前通过多层螺旋CT详细了解左心房顶部结构是改良消融技术，提高手术成功率、降低并发症的关键措施[77]。

左心耳起源于原始左心房，是沿左心房前侧壁向前下延伸的狭长弯曲的盲端结构[81]，长度为20～60 mm，宽度为16～59 mm[82]。左心耳开口多位于左心房前壁，部分位于左心房侧壁[83]；大多呈椭圆形，部分呈脚印形、圆形、水滴形、三角形[84]；口径变化较大（5～20 mm）[85]。多层螺旋CT和3D-TEE测得的左心耳开口最大径差异无统计学意义[86]。刘桂剑等[87]发现，左心耳入口内径、长度、射血速率与身高、房颤病史长短、左心房前后径等多种因素相关。CT影像上，左心耳呈"鸡翅型""仙人掌型""风向标型""菜花型"。Meta分析[88]提示，"鸡翅型"左心耳的房颤患者发生心房内血栓、短暂性脑缺血发作或卒中的风险低于非"鸡翅型"，但"鸡翅型"左心耳封堵术难度大于非"鸡翅型"。Yamada等[89]发现，左心耳分叶数≥3个的非瓣膜性房颤患者左心耳更易形成血栓，可能与其分叶数目越多、血液瘀滞的可能性越大有关，即左心耳的形状及分叶数目是心耳内血栓形成的独立危险因素。窦性心律情况下，左心耳具有正常的收缩及排空能力，很少形成血栓[90]。对于房颤患者，左心房不能正常节律性收缩，其内血流速率显著下降，左心耳排空不充分且左心耳口为缩窄状，血液容易滞留、凝固，进而加速血栓形成[91]。高达14%的急性房颤患者左心耳存在血栓[84]；左心耳是房颤患者血栓形成的最常见部位[92]，在非瓣膜性房颤患者中，91%以上的左心房血栓位于左心耳[93]。随着左心耳容积增大，血栓发生率升高[94]，且左心耳容积增大是房颤患者首次射频消融术后复发的独立危险因素；左心耳容积＞9.25 mL预测房颤射频消融术后复发的灵敏度为85.2%、特异度为67.9%[95]。Kuronuma等[96]在评估320排冠脉CTA诊断左心耳血栓的性能后发现，早期扫描基础上增加延迟扫描可提高左心耳血栓诊断的准确度。多排CT增强扫描诊断左心耳血栓形成的灵敏度可达96%、特异度达92%、阳性预测值达41%[97]。心脏CT属于无创检查，已逐渐取代了TEE[98]。但CTA也有自身局限性：不能直观区别血液瘀滞和血栓，容易造成假阳性结果[70]；有辐射性；无法对造影剂过敏的患者进行检查；在手术过程中无法实时监测[1]；对左心耳梳状肌与小血栓的区分较难。

2.3　主动脉窦　主动脉窦为主动脉根部最薄弱处，分为右冠窦、左冠窦与无冠窦。右冠窦坐于室间隔肌部嵴顶，邻接右房与右室，借圆锥间隔与右室流出道相邻；左冠窦邻接左心房、肺动脉根部和右室流出道后上间隔；无冠窦邻接右房与左心房[99]。De Heer等[100]发现，主动脉窦的形态在舒张期和收缩期无明显变化，高血压、性别、年龄对主动脉窦的大小有一定的影响[101]。主动脉窦相关房性心动过速中以无冠窦相关右房房性心动过速最多见。因无冠窦无His束毗邻，有利于起源于His束的心律失常消融。主动脉瓣环与窦管交界处之间的主动脉窦扩张可形成主动脉窦瘤[102]，以右冠窦好发，其次为无冠窦、左冠窦[103-104]，可通过超声心动图、心脏CT及MRI[105]确诊。其中，经胸超声心动图、TEE可明确主动脉窦瘤大小、部位、破入腔室和血流动力学的改变[106]；心脏CT三维重建是制定手术方案和手术结果风险分层的首选影像学方法[104]。Utsunomiya等[107]认为，多层螺旋CT较超声心动图能提供更好的主动脉窦三维影像，帮助电生理专家更准确了解主动脉窦相关解剖结构。

综上所述，CT作为一种常用的影像学检查方法，已广泛应用于心血管疾病的检查。通过多层螺旋CT测量卵圆窝、肺静脉、下腔静脉、冠状窦等多种解剖结构之间的距离，进而分析各解剖结构之间的关系，能帮助术者制定更精准的手术方案。对于心房及相邻解剖结构的解剖变异检查，CT较超声更精确，较MRI更便宜，可作为首选检查手段。多层螺旋CT不仅可以展现正常心脏电生理解剖结构，也可显示各结构的毗邻关系及生理性差异，加

深临床对心房解剖的认识，进而降低消融术中心肌穿孔、房室传导阻滞、心房-食管瘘等不良事件的发生风险，提高消融术的成功率。

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