



**The use of cardiac computed tomography angiography
in the assessment of percutaneous left atrial appendage
closure – Review and experts recommendations
endorsed by the Société française d'imagerie cardiaque
et vasculaire diagnostique et interventionnelle**

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The use of cardiac computed tomography angiography in the assessment of a percutaneous left atrial appendage closure – Review and experts recommendations endorsed by the Société Française d'Imagerie Cardiaque et Vasculaire diagnostique et interventionnelle

CT and percutaneous left atrial appendage closure – Review and recommendations endorsed by the SFICV

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Abstract

Atrial fibrillation is the most common cause of arrhythmia that is responsible for over 15% of ischemic strokes, most of these being secondary to migration of a left atrial appendage (LAA) thrombus. In patient with contraindication to anticoagulant therapy, percutaneous closure system placement may be indicated. Cardiac computed tomography (CT) angiography plays a central role in the initial assessment as well as in the follow-up. The purpose of the pre-implantation cardiac CT angiography is to evaluate the anatomy of the LAA in order to select the most suitable prosthesis and check for any contraindication to device implantation. Image analysis is divided into four steps that include analysis of the approach; search for a thrombus in the LAA; investigation of the anatomy of the LAA (morphology of the LAA, dimensions of the LAA and choice of device) and cardiac and thoracic assessments. Follow-up involves CT examination to check the position of the device and to detect any complications. On the basis of the results of currently available published research, a panel of experts has issued recommendations regarding cardiac CT angiography prior to percutaneous LAA closure device placement, which were further endorsed by the Société Française d'Imagerie Cardiaque et Vasculaire Diagnostique et Interventionnelle (SFICV).

List of abbreviations

AF: Atrial fibrillation; AO: Anatomical orifice; CT: Computed tomography; ECG: Electrocardiogram; IZ: Implantation zone (or "landing zone"); LAA: Left atrial appendage; LAAC: LAA closure; SFICV: Société Française d'Imagerie Cardiaque et Vasculaire diagnostique et interventionnelle; TEE: Transesophageal echocardiography

Mesh terms (There are five index terms)

Vascular disease;

Atrial appendage;

Thromboembolism;

Cardiac imaging technique;

1. Introduction

Atrial fibrillation (AF) is the most common arrhythmia and represents a public health issue with a projected incidence of up to 215,000 persons per year in Europe by 2030 [1]. AF is common among the elderly and affects 30% of people over the age of 60 years [2]. AF is responsible for over 15% of ischemic strokes and 25% of strokes between the ages of 80 and 89 years [3]. In 90% of strokes, they are secondary to the migration of a thrombus from the left atrial appendage (LAA) whose formation was promoted by nonvalvular AF [4].

Oral anticoagulants are the most effective prophylactic treatment of LAA thrombus [5]; however they are generally underused due to the rigorous adherence required, their adverse effects and the narrowed therapeutic window [6]. Their administration is accompanied by a risk of hemorrhage and contraindications are common, especially in the elderly. Alternatives to oral anticoagulant therapy are surgical ligation of the LAA that significantly reduces the risk of stroke [7], radiofrequency ablation of AF or, more recently, LAA percutaneous occlusion whose first implantation in humans was reported in 2001 [8, 9]. Two randomized trials have demonstrated the efficacy and safety of percutaneous LAA closure devices (LAAC) [10-12].

This document has been developed by ten experienced radiologists in cardiac imaging and two cardiologists involved in LAAC implantation. Based on the review of currently available published research and expert consensus, this document reflects the opinion of experts endorsed by the Société Française d'Imagerie Cardiaque et Vasculaire diagnostique et interventionnelle (SFICV) on imaging protocol, recommendations, a standardized analysis and a structured report involved in LAAC procedures for the radiologists.

2. Indication for percutaneous left atrial appendage occlusion

LAAC is considered in patients with nonvalvular AF with contraindication to anticoagulant therapy [13]. In France, approximatively the number of persons eligible for percutaneous LAA occlusion is about 10, 000 to 30, 000 patients per year [14]. In 2020, the European Society of Cardiology recommendations have proposed LAAC as a therapeutic alternative in patients with AF and presenting a contraindication to anticoagulant therapy (Class IIb recommendation) [15]. The indication of LAAC is relevant in patients with AF with a definite

and permanent contraindication to anticoagulants (validated by a multidisciplinary panel) and with high thromboembolic risk defined as a CHA₂DS-VASc score ≥ 4 [16].

3. Technique

3.1. LAAC devices

Various models of percutaneous prostheses exist but two are predominantly used to exclude the LAA. They are the Watchman FLX[™] device (Boston Scientific) and the Amplatzer[™] Amulet[™] device (Abbott Vascular) [17, 18].

3.1.1. The Watchman FLX[™] device

The Watchman FLX[™] device is the last generation of the Watchman device. The prosthesis consists of a cage-shaped nitinol frame structure partially covered with polyethylene terephthalate at its base and lateral edge. It rests against the internal face of the LAA (Supplemental Figure S1). Several observational studies and registries described the sizing measurements and the size of the device as well as the implantation modality of the device [19-23].

3.1.2. The Amplatzer[™] Amulet[™] device

The self-expanding braided nitinol mesh prosthesis consists of an external disc resting against the atrial face of the LAA and an internal lobe positioned at the base of the LAA, with both parts linked by a central waist (Supplemental Figure S2). Characteristics of the device as well as its method of implantation have been described in several observational studies and registries [24-27].

3.2. Positioning the device

The pre-implantation (or pre-LAAC) assessment consists of a blood test (coagulation panel and serum creatinine value) and a cardiac computed tomography (CT) angiography [28]. Transesophageal echocardiography (TEE) is almost always performed during system implantation. The procedure is performed under anesthesia (usually general) in an interventional imaging suite. An introducer sheath is placed in the right common femoral vein via femoral venous access. The device is contained in a support sheath mounted in the right atrium then introduced into the left atrium through an inter-atrial septum crossing. The device

is then deployed under fluoroscopic and ultrasound guidance. In most cases the intervention takes place smoothly.

3.3. Pre-implantation imaging modalities

The imaging assessment includes cardiac CT angiography performed prior to implantation and TEE performed during the procedure [29]. Although TEE has been considered as the gold standard, the three-dimensional nature of CT improves the accuracy for guiding the choice of LAAC device [30-33]. It reduces the rate of peri-interventional complications compared to the TEE by improving the choice of prosthesis size. Investigating LAA with TEE rather than with CT might results in underestimation of the ostial dimensions and depth of the LAA [8]. Lastly, CT enables vascular approach, transeptal puncture site and circumflex artery location to be anticipated prior to implantation [34].

3.4. CT image acquisition protocol prior to LAAC

The purpose of pre-implantation cardiac CT angiography is to evaluate the anatomy of the LAA in order to select the most suitable prosthesis and check for any contraindications to introducing the device. Patients should be preferably in a nonfasting state. Imaging has been recommended to be performed using CT unit with at least 64 rows of detectors, with electrocardiogram (ECG)-gating [35]. Both prospective and retrospective ECG-gating have been used for all pre-procedural imaging acquisitions [35]. Prospective ECG gating is more sensitive to cardiac arrhythmia and does not allow post hoc reconstruction of cardiac phases, but the radiation exposure is significantly reduced compared with retrospective ECG gating. Images should be obtained in a phase corresponding to 30-60% of the R-R interval to reduce radiation exposure [36]. Based on currently available published research and experts consensus, we recommend a prospective triphasic ECG-gated acquisitions with a spontaneous contrast phase followed with an arterial and a venous phases (70 s post-injection) with 1 mL of iodinated contrast material per kg (concentration ≥ 350 mg iodine/mL) at a rate of 4-5 mL/s flushed with 50 mL of saline solution [37]. The non-enhanced phase may be considered for adjustment of the field of view before contrast media injection [37, 38]. Acquisition during the venous phase is useful if filling of the LAA for the arterial phase is incomplete (a frequent situation) and if the presence of a thrombus in the LAA cannot be ruled out. Dual-energy CT is also valuable for differentiating between delayed opacification and a thrombus [39].

All these parameters are noted in the suggested standardized report detailed in Table 1. In case of contraindication of iodinated contrast media injection, cardiac magnetic resonance imaging is a valuable tool for detecting intra-LAA thrombus [40].

3.5. Image analysis

For consistency in image analysis and report, we recommend four steps in image analysis as in the standardized report (Table 1): analysis of the approach, search for a thrombus in the LAA, investigating LAA anatomy, and cardiac and thoracic assessments.

3.5.1. Analysis of the approach

Analysis of the approach includes examining the inferior vena cava included in the field of view and the right atrium, through which the device passes. The interatrial septum (IAS) should also be analyzed for abnormality (interatrial communication, mass, thrombus, etc.) or anatomical variation (interatrial septal aneurysm, patent *foramen ovale*, lipomatous hypertrophy of the interatrial septum that may interfere with the transseptal puncture (Supplemental Figure S3). The IAS analysis provides optimal transseptal puncture position choice to allow device and LAA alignment.

3.5.2. Search for a thrombus in the LAA

The presence of a thrombus in the LAA is a contraindication for device placement. It manifests as a hypo attenuating structure partially or totally occupying in the LAA, visible on the arterial phase acquisition and persisting on the venous phase acquisition (Supplemental Figure S4). It is important to differentiate between delayed filling of the LAA and a thrombus. A delay in opacification presents as an LAA opacification defect that disappears in the venous phase. This is almost always due to a large volume left atrium circulating slowly. The ratio of iodinated contrast material attenuation/native blood attenuation is indicative of stasis, not thrombus but the ratio cut-offs vary substantially between publications, making clinical application using the ratio alone difficult [41-43]. When two acquisitions (arterial and venous) are performed, the sensitivity, specificity and negative predictive value of CT for detecting a thrombus in the LAA are 97%, 100% and 97%, respectively [43, 44].

3.5.3. Investigating the LAA anatomy

This step analyzes the overall morphology of the LAA, its dimensions and its relationship to the left circumflex artery that is potential risk of compression by the device. The analysis is preferably performed in the ventricular systolic phase to ensure maximum atrial filling. The LAA appears on the scan as a blind structure, often pyramidal in shape, with extensions known as lobes [45]. Its anatomy and dimensions vary widely among individuals, without any correlation with patient size and gender [46]. The CT report must specify:

3.5.3. 1. LAA morphology

LAA morphology can be seen on multiplanar reconstruction and three-dimensional volume reconstructions. Wang et al. described 4 different morphologies: the "chicken wing" type (Supplemental Figure S5), the most common type (48% of patients), the "cactus" type (30% of patients) (Supplemental Figure S6); the "windsock" type (19% of patients) (Supplemental Figure S7) and the "cauliflower" type (3% of patients) (Supplemental Figure S8) [21]. The "cauliflower" type is associated with a higher embolic risk while the "chicken wing" type represents the least risk [47-49]. The latter also seems to be the most problematic for LAAC device implantation because of its sharp angulation [50]. The number of lobes of the LAA must also be specified as the presence of several lobes may compromise the device's seal. There are usually two lobes (54% of patients) (Supplemental Figure S9). More rarely, one lobe (20% of patients), 3 lobes (25% of patients) and rarely 4 lobes (< 10% of patients) are found [46]. The presence of a lobe emerging from the base of the LAA must also be reported as this may lead to a leak in the LAA closure device. Such lobe has to be distinguished from accessory appendage [51].

3.5.3.2. LAA dimensions

Each device manufacturer provides its own guidelines for determining the sizing of device to implant [25, 26, 52, 53]. The LAA is measured in double oblique view to distinguish a slice passing through the LAA, the left upper pulmonary vein and the circumflex artery (Figure 1) [54]. Kirchhof et al. suggest obtaining this slice by successively applying a right anterior obliquity of 30° on the axial slice and a cranial obliquity of 10° on the sagittal plane [6]. The pre-implantation CT measurements to be taken for the 2 types of device are: (i), measurement of the anatomical orifice (AO): This is located at the junction between the LAA and the right atrium. The large and small diameters must be measured (Figure 2); and (ii), measurement of

the implantation zone (IZ) (or "landing zone"): This is located at the entrance of the main lobe where the device provides a perfect seal because it is confined by the LAA walls. It is usually measured at approximately 10 mm from the AO. The large and small diameters must be noted (Figure 3).

Additional measurements specific to each device are also required. For the Watchman system this is the maximum depth of the LAA corresponding to the distance between the center of the anatomical orifice and the apex of the main lobe, the latter being unfolded over a double oblique slice (Figure 4). For the Amplatzer Amulet system, the direct depth must be measured. This is the orthogonal distance between the center of the anatomical orifice and the adjacent base of the LAA (Figure 5). Figure 6 summarizes all the dimensions to be recorded according to the device type.

3.5.3.3. Selection of device

Measurements on CT images depend on the type of prosthesis. For the Watchman device, the size of the device is selected by oversizing the large diameter of the landing zone of the LAA by 10 to 30 % using a specific table available on the manufacturer's site. There are five different sizes ranging from 20- to 35 mm in diameter. The length of the device must be less than the maximum depth of the LAA. For the Amulet, the largest diameter of the landing zone is oversized by 3- to 6 mm. The depth of the device must be at least 2.5 mm less than the depth of the LAA. There are 8 different diameter sizes ranging from 16 to 34 mm.

3.5.4. Cardiac and thoracic assessments

In addition to AAG related procedure assessment, CT helps perform coronary calcium score quantification with the first enhanced ECG-gated examination and eventually add coronary heart disease risk estimation in those patients. Coronary analysis may be performed when image quality allows its analysis because CT image quality may be impaired in patients with AF [55]. This information may modify patients care management [56, 57]. CT allows the assessment of the entire cardiac mass and all adjacent structures such as mediastinum, vascular anatomy, pulmonary parenchyma, upper abdominal slices, bone structures to search for incidental abnormalities [58, 59].

3.6. Peri-procedural LAAC device related complications

Per-intervention complications have been reported such as perforation of the LAA responsible for hemopericardium with tamponade (if the device is oversized), migration of the device (if the device is undersized), that could be immediately been detected with TEE. When suspected, early complications such as compression of the circumflex artery by the device responsible for myocardial ischemia, gas embolism, infection and hematoma at the puncture point can be depicted with CT [28, 55]. Other complication as stroke/transient ischemic attack are explored with CT and /or magnetic resonance imaging. Late complications such as migration of the device, major or minor peri-prosthetic leak or atrial thrombus are better depicted with CT than with TEE [60].

3.7. CT-related radiation exposure

Mean radiation with standard cardiac protocol is less than 3 mSv [42, 61, 62]. The advent of low-dose acquisition as well as hybrid reconstruction may lower the radiation dose delivered to the patient [63, 64].

4. Follow-up

No consensus or guidelines are available regarding the imaging follow-up after LAAC procedure (modality and frequency). Routinely, imaging follow-up is performed by TEE at 24-48 h to identify any pericardial effusion that may suggest rupture or migration of the system. After the hospital stay, follow-up involves regular scanning to check the correct position of the device and detect any migration (Supplemental Figure S10) [61, 65, 66]. The formation of a thrombus in contact with the atrial face of the system (Supplemental Figure S11), a rare but potentially serious complication, should also be recorded [61]. Its presence imposes that anticoagulant treatment must be introduced. CT-scanner should also look for residual opacification of the LA (Supplemental Figure S12), which is found in more than 50% of patients, reflecting a system leak whose clinical impact remains controversial [67]. Complete or partial, it may be visible from the arterial phase or only in the venous phase [68]. It should be noted that CT appears more sensitive than TEE in detecting leaks after device implantation [69, 70].

5. Conclusion

This review with recommendations (Table 2) and a standardized report is a support for the clinician workflow for pre-planning and follow-up cardiac computed tomography angiography for LAAC procedure.

Human rights

The authors declare that the work described has been carried out in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans.

Informed consent and patient details

The authors declare that this report does not contain any personal information that could lead to the identification of the patients.

Disclosure of interest

The authors declare that they have no competing interest.

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Author contributions

All authors attest that they meet the current International Committee of Medical Journal Editors (ICMJE) criteria for Authorship.

References

1. Zoni-Berisso M, Lercari F, Carazza T, Domenicucci S. Epidemiology of atrial fibrillation: European perspective. *Clin Epidemiol* 2014;6:213-220.
2. Chugh SS, Havmoeller R, Narayanan K, Singh D, Rienstra M, Benjamin EJ, et al. Worldwide epidemiology of atrial fibrillation: a global burden of disease 2010 Study. *Circulation* 2014;129:837-847.
3. Wang TJ, Massaro JM, Levy D, Vasan RS, Wolf PA, D'Agostino RB, et al. A risk score for predicting stroke or death in individuals with new-onset atrial fibrillation in the community: the Framingham Heart Study. *JAMA* 2003;290:1049-1056.
4. Wolf PA, Abbott RD, Kannel WB. Atrial fibrillation as an independent risk factor for stroke: the Framingham Study. *Stroke* 1991;22:983-988.
5. Hart RG, Pearce LA, Aguilar MI. Meta-analysis: antithrombotic therapy to prevent stroke in patients who have nonvalvular atrial fibrillation. *Ann Intern Med* 2007;146:857-867.
6. Kirchhof P, Benussi S, Kotecha D, Ahlsson A, Atar D, Casadei B, et al. 2016 ESC Guidelines for the management of atrial fibrillation developed in collaboration with EACTS. *Europace* 2016;18:1609-1678.
7. Blackshear JL, Odell JA. Appendage obliteration to reduce stroke in cardiac surgical patients with atrial fibrillation. *Ann Thorac Surg* 1996;61:755-759.
8. Sievert H, Lesh MD, Trepels T, Omran H, Bartorelli A, Della Bella P, et al. Percutaneous left atrial appendage transcatheter occlusion to prevent stroke in high-risk patients with atrial fibrillation: early clinical experience. *Circulation* 2002;105:1887-1889.

9. Moussa Pacha H, Al-Khadra Y, Soud M, Darmoch F, Moussa Pacha A, Alraies MC. Percutaneous devices for left atrial appendage occlusion: A contemporary review. *World J Cardiol* 2019;11:57-70.
10. Reddy VY, Doshi SK, Kar S, Gibson DN, Price MJ, Huber K, et al. 5-year outcomes after left atrial appendage closure: from the PREVAIL and PROTECT AF trials. *J Am Coll Cardiol* 2017;70:2964-2975.
11. Reddy VY, Sievert H, Halperin J, Doshi SK, Buchbinder M, Neuzil P, et al. Percutaneous left atrial appendage closure vs warfarin for atrial fibrillation: a randomized clinical trial. *JAMA* 2014;312:1988-1998.
12. Holmes DR, Jr., Kar S, Price MJ, Whisenant B, Sievert H, Doshi SK, et al. Prospective randomized evaluation of the Watchman left atrial appendage closure device in patients with atrial fibrillation versus long-term warfarin therapy: the PREVAIL trial. *J Am Coll Cardiol* 2014;64:1-12.
13. Holmes DR, Reddy VY, Turi ZG, Doshi SK, Sievert H, Buchbinder M, et al. Percutaneous closure of the left atrial appendage versus warfarin therapy for prevention of stroke in patients with atrial fibrillation: a randomised non-inferiority trial. *Lancet* 2009;374:534-542.
14. Santé CdlHAD. Evaluation de l'occlusion de l'appendice auriculaire gauche par voie transcutanée. Haute Autorité de Santé (HAS). 2014.
15. Hindricks G, Potpara T, Dagres N, Arbelo E, Bax JJ, Blomstrom-Lundqvist C, et al. 2020 ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS). *Eur Heart J* 2021;42:373-498.

16. HAS. Evaluation de l'occlusion de l'appendice auriculaire gauche par voie transcutanée. Haute Autorité de Santé. 2014; Saint-Denis La Plaine. https://www.has-sante.fr/upload/docs/application/pdf/2014-09/texte_court_occlusion_transcutanee_aag.pdf (Accessed on May 25, 2021)
17. Staubach S, Schlatterbeck L, Mortl M, Strohm H, Hoppmann P, Laugwitz KL, et al. Long-term transesophageal echocardiography follow-up after percutaneous left atrial appendage closure. *Heart Rhythm* 2020;17:728-733.
18. Asmarats L, Rodes-Cabau J. Percutaneous left atrial appendage closure: current devices and clinical outcomes. *Circ Cardiovasc Interv* 2017;10: e005359.
19. Masoudi FA. The evolution of left atrial appendage occlusion: EWOLUTION and the WATCHMAN in practice. *Eur Heart J* 2016;37:2475-2477.
20. Boersma LV, Schmidt B, Betts TR, Sievert H, Tamburino C, Teiger E, et al. Implant success and safety of left atrial appendage closure with the WATCHMAN device: periprocedural outcomes from the EWOLUTION registry. *Eur Heart J* 2016;37:2465-2474.
21. Wang DD, Eng M, Kupsy D, Myers E, Forbes M, Rahman M, et al. Application of 3-dimensional computed tomographic image guidance to WATCHMAN implantation and impact on early operator learning curve: single-center experience. *JACC Cardiovasc Interv* 2016;9:2329-2340.
22. Eng MH, Wang DD. Computed tomography for left atrial appendage occlusion case planning. *Interv Cardiol Clin* 2018;7:367-378.
23. Kaafarani M, Saw J, Daniels M, Song T, Rollet M, Kesinovic S, et al. Role of CT imaging in left atrial appendage occlusion for the WATCHMAN device. *Cardiovasc Diagn Ther* 2020;10:45-58.

24. Aminian A, Schmidt B, Mazzone P, Berti S, Fischer S, Montorfano M, et al. Incidence, characterization, and clinical Impact of device-related thrombus following left atrial appendage occlusion in the prospective global AMPLATZER amulet observational study. *JACC Cardiovasc Interv* 2019;12:1003-1014.
25. Landmesser U, Tondo C, Camm J, Diener HC, Paul V, Schmidt B, et al. Left atrial appendage occlusion with the AMPLATZER Amulet device: one-year follow-up from the prospective global Amulet observational registry. *EuroIntervention* 2018;14:e590-e597.
26. Landmesser U, Schmidt B, Nielsen-Kudsk JE, Lam SCC, Park JW, Tarantini G, et al. Left atrial appendage occlusion with the AMPLATZER Amulet device: periprocedural and early clinical/echocardiographic data from a global prospective observational study. *EuroIntervention* 2017;13:867-876.
27. Clemente A, Avoglierio F, Berti S, Paradossi U, Jamagidze G, Rezzaghi M, et al. Multimodality imaging in preoperative assessment of left atrial appendage transcatheter occlusion with the Amplatzer Cardiac Plug. *Eur Heart J Cardiovasc Imaging* 2015;16:1276-1287.
28. Rajwani A, Nelson AJ, Shirazi MG, Disney PJS, Teo KSL, Wong DTL, et al. CT sizing for left atrial appendage closure is associated with favorable outcomes for procedural safety. *Eur Heart J Cardiovasc Imaging* 2017;18:1361-1368.
29. Rajiah P, Alkhouli M, Thaden J, Foley T, Williamson E, Ranganath P. Pre- and postprocedural CT of transcatheter left atrial appendage Closure devices. *Radiographics* 2021;41:680-698.

30. Chow DH, Bieliauskas G, Sawaya FJ, Millan-Iturbe O, Kofoed KF, Sondergaard L, et al. A comparative study of different imaging modalities for successful percutaneous left atrial appendage closure. *Open Heart* 2017;4:e000627.
31. Saw J, Fahmy P, Spencer R, Prakash R, McLaughlin P, Nicolaou S, et al. Comparing measurements of CT angiography, TEE, and fluoroscopy of the left atrial appendage for percutaneous closure. *J Cardiovasc Electrophysiol* 2016;27:414-422.
32. Eng MH, Wang DD, Greenbaum AB, Gheewala N, Kupsky D, Aka T, et al. Prospective, randomized comparison of 3-dimensional computed tomography guidance versus TEE data for left atrial appendage occlusion (PRO3DLAAO). *Catheter Cardiovasc Interv* 2018;92:401-407.
33. Morcos R, Al Taii H, Bansal P, Casale J, Manam R, Patel V, et al. Accuracy of commonly-used imaging modalities in assessing left atrial appendage for interventional closure: review article. *J Clin Med* 2018;7:441.
34. Ismail TF, Panikker S, Markides V, Foran JP, Padley S, Rubens MB, et al. CT imaging for left atrial appendage closure: a review and pictorial essay. *J Cardiovasc Comput Tomogr* 2015;9:89-102.
35. Korsholm K, Jensen JM, Nielsen-Kudsk JE. Cardiac Computed Tomography for Left atrial appendage Occlusion: acquisition, analysis, advantages, and Limitations. *Interv Cardiol Clin* 2018;7:229-242.
36. Patel AR, Fatemi O, Norton PT, West JJ, Helms AS, Kramer CM, et al. Cardiac cycle-dependent left atrial dynamics: implications for catheter ablation of atrial fibrillation. *Heart Rhythm* 2008;5:787-793.

37. Korsholm K, Berti S, Iriart X, Saw J, Wang DD, Cochet H, et al. Expert recommendations on cardiac computed tomography for planning transcatheter left atrial appendage occlusion. *JACC Cardiovasc Interv* 2020;13:277-292.
38. Bilchick KC, Meador A, Gonzalez J, Norton P, Zhuo D, Mason P, et al. Effectiveness of integrating delayed computed tomography angiography imaging for left atrial appendage thrombus exclusion into the care of patients undergoing ablation of atrial fibrillation. *Heart Rhythm* 2016;13:12-19.
39. Hur J, Kim YJ, Lee HJ, Nam JE, Hong YJ, Kim HY, et al. Cardioembolic stroke: dual-energy cardiac CT for differentiation of left atrial appendage thrombus and circulatory stasis. *Radiology* 2012;263:688-695.
40. Chen J, Zhang H, Zhu D, Wang Y, Byanju S, Liao M. Cardiac MRI for detecting left atrial/left atrial appendage thrombus in patients with atrial fibrillation: meta-analysis and systematic review. *Herz* 2019;44:390-397.
41. Kim SC, Chun EJ, Choi SI, Lee SJ, Chang HJ, Han MK, et al. Differentiation between spontaneous echocardiographic contrast and left atrial appendage thrombus in patients with suspected embolic stroke using two-phase multidetector computed tomography. *Am J Cardiol* 2010;106:1174-1181.
42. Spagnolo P, Giglio M, Di Marco D, Cannao PM, Agricola E, Della Bella PE, et al. Diagnosis of left atrial appendage thrombus in patients with atrial fibrillation: delayed contrast-enhanced cardiac CT. *Eur Radiol* 2021;31:1236-1244.
43. Romero J, Cao JJ, Garcia MJ, Taub CC. Cardiac imaging for assessment of left atrial appendage stasis and thrombosis. *Nat Rev Cardiol* 2014;11:470-480.

44. Romero J, Husain SA, Kelesidis I, Sanz J, Medina HM, Garcia MJ. Detection of left atrial appendage thrombus by cardiac computed tomography in patients with atrial fibrillation: a meta-analysis. *Circ Cardiovasc Imaging* 2013;6:185-194.
45. Naksuk N, Padmanabhan D, Yogeswaran V, Asirvatham SJ. Left atrial appendage: embryology, anatomy, physiology, arrhythmia and therapeutic intervention. *JACC Clin Electrophysiol* 2016;2:403-412.
46. Veinot JP, Harrity PJ, Gentile F, Khandheria BK, Bailey KR, Eickholt JT, et al. Anatomy of the normal left atrial appendage: a quantitative study of age-related changes in 500 autopsy hearts: implications for echocardiographic examination. *Circulation* 1997;96:3112-3115.
47. Wang Y, Di Biase L, Horton RP, Nguyen T, Morhanty P, Natale A. Left atrial appendage studied by computed tomography to help planning for appendage closure device placement. *J Cardiovasc Electrophysiol* 2010;21:973-982.
48. Lupercio F, Carlos Ruiz J, Briceno DF, Romero J, Villablanca PA, Berardi C, et al. Left atrial appendage morphology assessment for risk stratification of embolic stroke in patients with atrial fibrillation: a meta-analysis. *Heart Rhythm* 2016;13:1402-1409.
49. Romero J, Natale A, L DIB. Left atrial appendage morphology and physiology: "the missing piece in the puzzle". *J Cardiovasc Electrophysiol* 2015;26:928-933.
50. Di Biase L, Santangeli P, Anselmino M, Mohanty P, Salvetti I, Gili S, et al. Does the left atrial appendage morphology correlate with the risk of stroke in patients with atrial fibrillation? Results from a multicenter study. *J Am Coll Cardiol* 2012;60:531-538.
51. Abbara S, Mundo-Sagardia JA, Hoffmann U, Cury RC. Cardiac CT assessment of left atrial accessory appendages and diverticula. *AJR Am J Roentgenol* 2009;193:807-812.

52. Xu B, Betancor J, Sato K, Harb S, Abdur Rehman K, Patel K, et al. Computed tomography measurement of the left atrial appendage for optimal sizing of the Watchman device. *J Cardiovasc Comput Tomogr* 2018;12:50-55.
53. Tzikas A, Gafoor S, Meerkin D, Freixa X, Cruz-Gonzalez I, Lewalter T, et al. Left atrial appendage occlusion with the AMPLATZER Amulet device: an expert consensus step-by-step approach. *EuroIntervention* 2016;11:1512-1521.
54. Korsholm K, Nielsen KM, Jensen JM, Jensen HK, Andersen G, Nielsen-Kudsk JE. Transcatheter left atrial appendage occlusion in patients with atrial fibrillation and a high bleeding risk using aspirin alone for post-implant antithrombotic therapy. *EuroIntervention* 2017;12:2075-2082.
55. Katona A, Temesvari A, Szatmari A, Nemes A, Forster T, Fontos G. Left circumflex coronary artery occlusion due to a left atrial appendage closure device. *Postepy Kardiol Interwencyjne* 2015;11:69-70.
56. Alkindi FA, Rafie IM. Anticoagulation in patients with atrial fibrillation and coronary artery disease. *Heart Views* 2020;21:32-36.
57. Knuuti J, Wijns W, Saraste A, Capodanno D, Barbato E, Funck-Brentano C, et al. 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes. *Eur Heart J* 2020;41:407-477.
58. Cellina M, Bombaci F, Gibelli D, Marta P, Oliva G. CT features of an uncommon association between coronary-pulmonary fistula and Vieussens' arterial ring. *Diagn Interv Imaging* 2020;101:499-500.
59. Raimondi F, Secinaro A, Boddaert N, Bonnet D. Imaging features of complete congenital atresia of left coronary artery. *Diagn Interv Imaging* 2020;101:421-423.

60. Masoud A, Bartoletti S, Fairbairn T, Khurana A, Velavan P, Morrison WL, et al. Outcome of left atrial appendage occlusion in high-risk patients. *Heart* 2018;104:594-599.
61. Saw J, Fahmy P, DeJong P, Lempereur M, Spencer R, Tsang M, et al. Cardiac CT angiography for device surveillance after endovascular left atrial appendage closure. *Eur Heart J Cardiovasc Imaging* 2015;16:1198-1206.
62. Gerber TC, Kantor B, McCollough CH. Radiation dose and safety in cardiac computed tomography. *Cardiol Clin* 2009;27:665-677.
63. Beregi JP, Greffier J. Low and ultra-low dose radiation in CT: opportunities and limitations. *Diagn Interv Imaging* 2019;100:63-64.
64. Greffier J, Boccalini S, Beregi JP, Vlassenbroek A, Vuillod A, Dupuis-Girod S, et al. CT dose optimization for the detection of pulmonary arteriovenous malformation (PAVM): a phantom study. *Diagn Interv Imaging* 2020;101:289-297.
65. Poulter RS, Tang J, Jue J, Ibrahim R, Nicolaou S, Mayo J, et al. Cardiac computed tomography follow-up of left atrial appendage exclusion using the Amplatzer Cardiac Plug device. *Can J Cardiol* 2012;28:119 e111-113.
66. Lakkireddy D, Windecker S, Thaler D, Sondergaard L, Carroll J, Gold MR, et al. Rationale and design for AMPLATZER amulet left atrial appendage Occluder IDE randomized controlled trial (Amulet IDE Trial). *Am Heart J* 2019;211:45-53.
67. Saw J, Tzikas A, Shakir S, Gafoor S, Omran H, Nielsen-Kudsk JE, et al. Incidence and clinical impact of device-associated thrombus and peri-device leak following left atrial appendage closure with the Amplatzer cardiac plug. *JACC Cardiovasc Interv* 2017;10:391-399.

68. Hornung M, Gafoor S, Id D, Vaskelyte L, Hofmann I, Franke J, et al. Catheter-based closure of residual leaks after percutaneous occlusion of the left atrial appendage. *Catheter Cardiovasc Interv* 2016;87:1324-1330.
69. Jaguszewski M, Manes C, Puippe G, Salzberg S, Muller M, Falk V, et al. Cardiac CT and echocardiographic evaluation of peri-device flow after percutaneous left atrial appendage closure using the AMPLATZER cardiac plug device. *Catheter Cardiovasc Interv* 2015;85:306-312.
70. Lim YM, Kim JS, Kim TH, Uhm JS, Shim CY, Joung B, et al. Delayed left atrial appendage contrast filling in computed tomograms after percutaneous left atrial appendage occlusion. *J Cardiol* 2017;70:571-577.

Figure legends

Figure 1: Reference arterial phase ECG-gated CT image in the sagittal oblique plane that allows analysis of the left atrial appendage in a patient with atrial fibrillation candidate for a left atrial appendage closure. The first step consists of showing the base, the main lobe, and the tip of the left atrial appendage (star) on a double oblique incidence including the circumflex artery (arrowhead) and the left upper pulmonary vein (arrow). A stent is present in the circumflex artery, resulting in few metal artifacts.

Figure 2: Arterial phase reference ECG-gated CT images allowing analysis of the anatomical orifice of the left atrial appendage. A, On the reference CT image in the sagittal oblique plane, the anatomical orifice of the left atrial appendage is represented with a red line. B, On CT image obtained in the orthogonal plane relative to A, the anatomical orifice is measured. The red lines represent the measurements of the large and small diameters of the anatomical orifice zone.

Figure 3: Reference arterial phase ECG-gated CT images allowing analysis of the left atrial appendage landing zone. A, On the reference CT image in the sagittal oblique plane, the left atrial landing zone is shown here as a red line, located 10 mm above the anatomical orifice. B, On CT image obtained in the orthogonal plane relative to A, the landing zone is measured. The red lines represent the measurements of the large and small diameters of the landing zone.

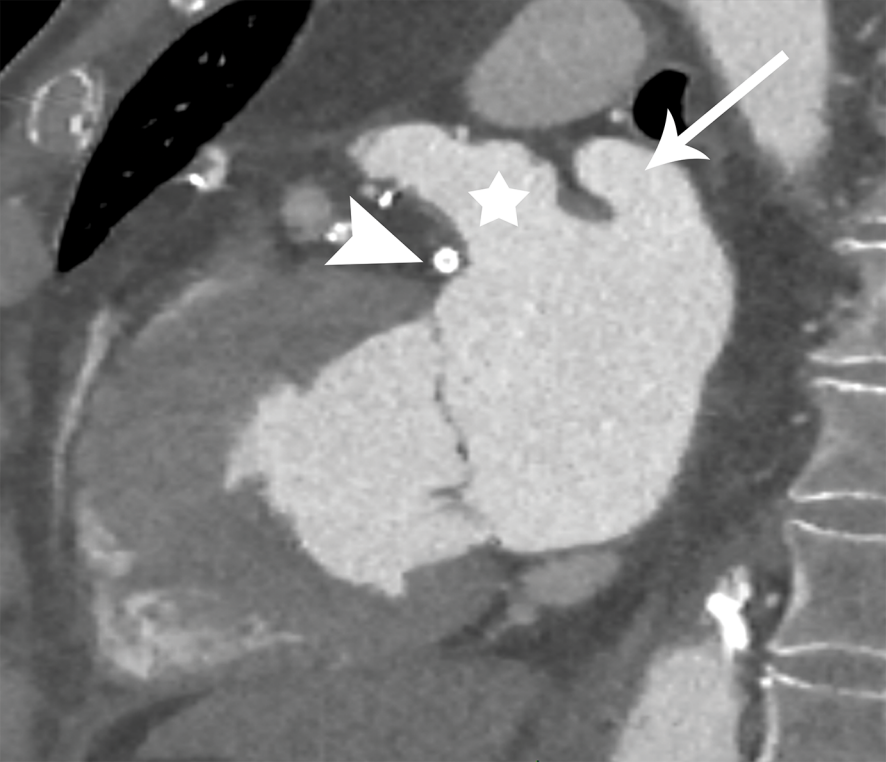
Figure 4: Reference arterial phase ECG-gated CT image in the sagittal oblique plane allowing analysis of the maximum depth of the left atrial appendage. On the reference slice, the thick white line represents the measurement of the maximum depth between the center of the anatomical orifice (thin white line) and the base of the main lobe of the left atrial appendage.

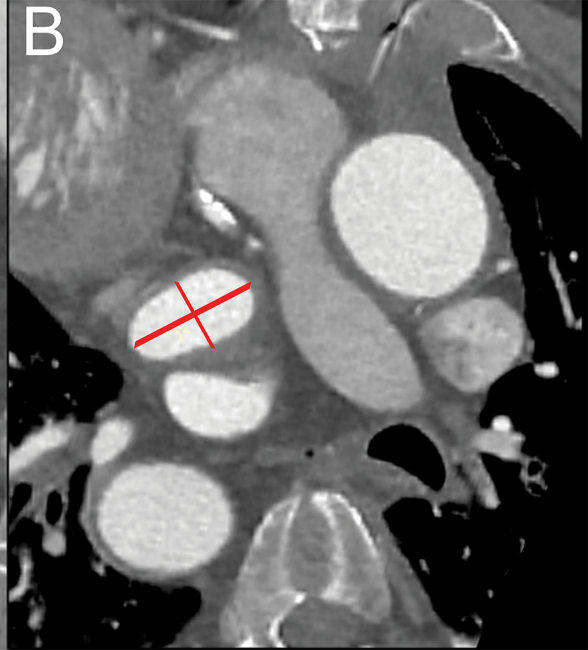
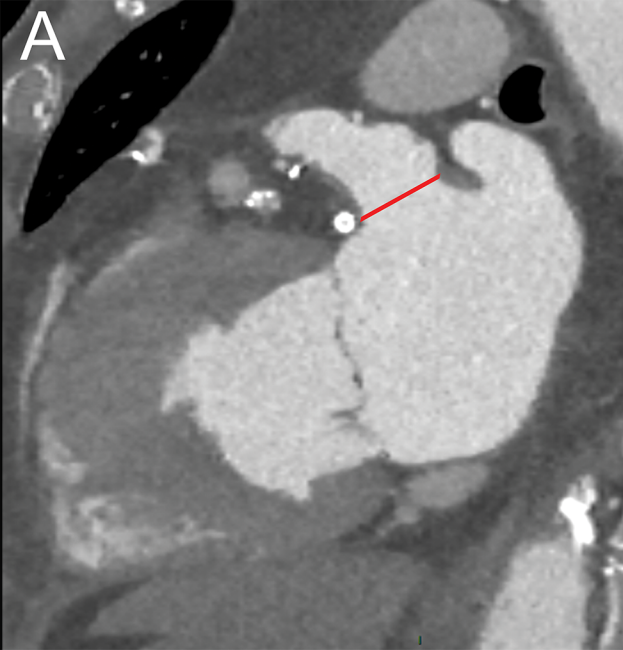
Figure 5: Reference arterial phase ECG-gated CT image in the sagittal oblique plane allowing analysis of the direct depth of the left atrial appendage. The fine white line represents the measurement of the direct perpendicular depth between the center of the anatomical orifice (thick white line) and the edge of the main lobe of the left atrial appendage.

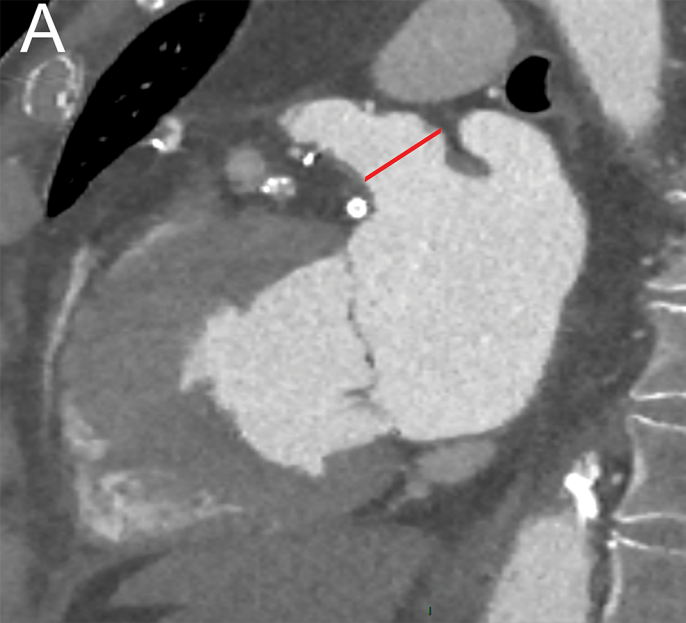
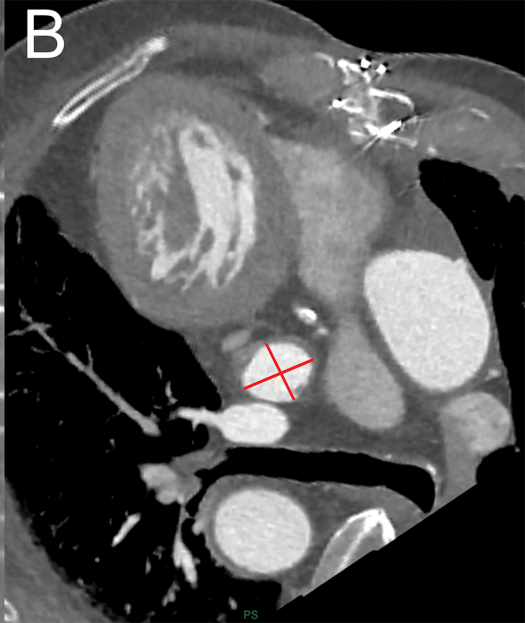
Figure 6: Diagram summarizing the measurements to be taken from the reference slice before implantation of a left atrial appendage closure device: the anatomical zone, the landing zone, the direct depth and the maximum depth.

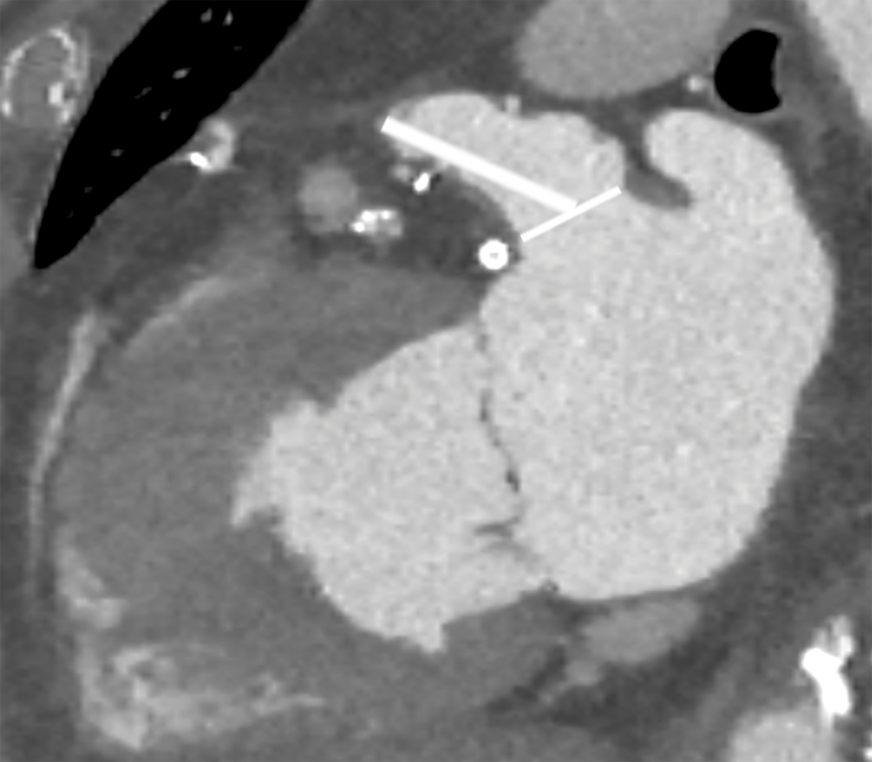
Table 1: Standardized CT report before left atrial appendage closure.

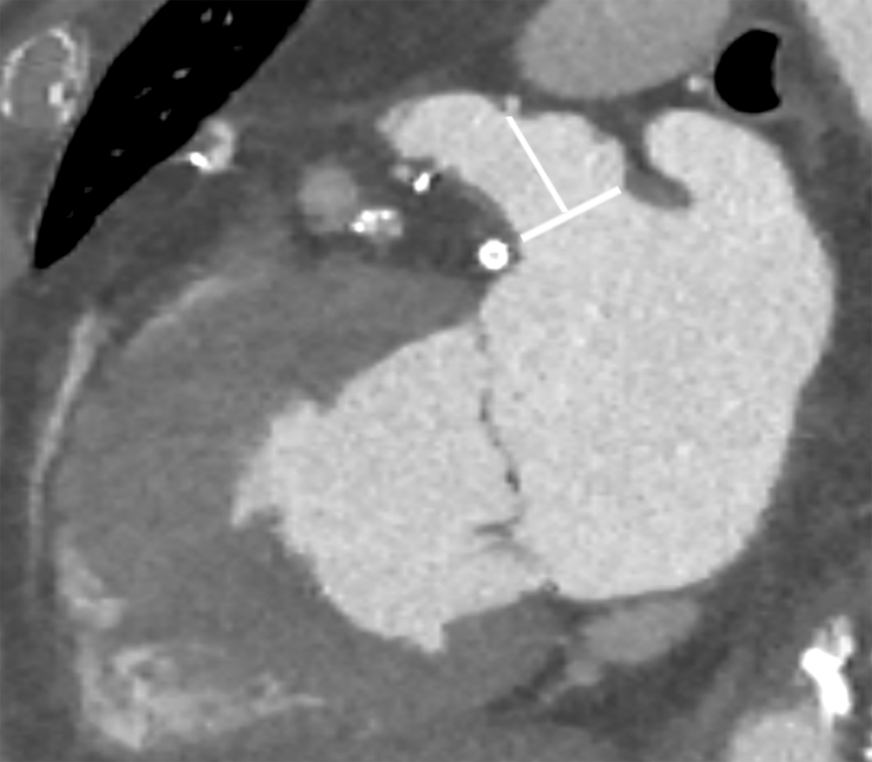
Table 2: Recommendations for CT work-up in patients candidate for LAAC device placement and for post LAAC device placement follow-up.





A**B**





Left upper pulmonary vein

Circumflex artery

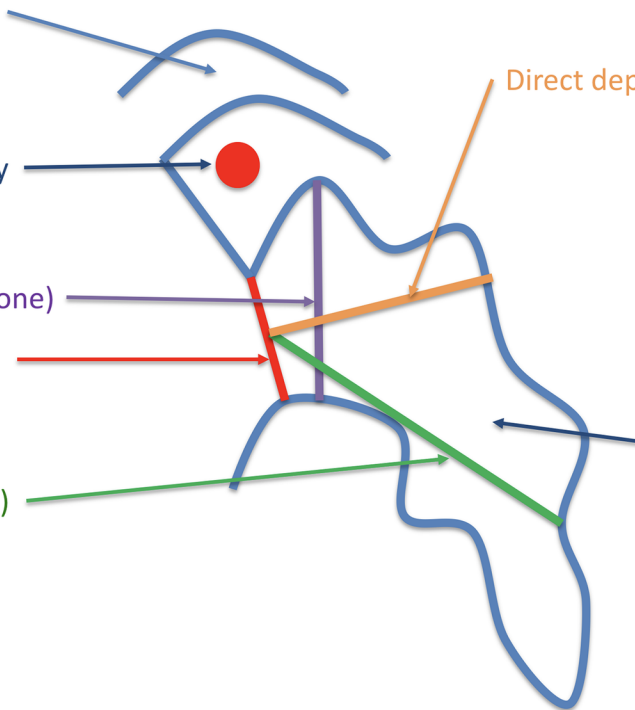
Direct depth (Amulet)

Implantation zone (landing zone)

External anatomical orifice

Left atrial appendage

Maximum depth (Watchman)



Indication:

CT assessment before left atrial appendage closure

Technique:

Acquisition in prospective/retrospective ECG-gated mode

In spontaneous contrast and in arterial and venous phases (70s post-injection)

Injection of XX mL of iodine contrast agent ... mg/mL.

Product used / amount injected (in mL)

Delivered dose of radiation DLP (mGy.cm)

Results:

Approach (inferior vena cava and right atrium) = abnormality?

Inter-atrial septum: aneurysm, lipomatous hypertrophy, other?

Thrombus in the LAA: yes/no

Anatomy of the LAA

- Morphology: chicken wing, cactus, windsock, cauliflower (produce VR reconstructions of the LAA)

- Number of lobes:

- Basal lobe: yes/no

Dimensions of the LAA (Figure 6)

- External anatomical orifice: ... × ... mm

- Landing zone: ... × ... mm

- Maximum depth (Watchman FLX): ... mm

- Direct depth (Amulet): ... mm

Coronary abnormalities: (course, stenosis, other)

Extra cardiac abnormalities:

Conclusion:

Typical anatomy of the inter-atrial septum. No obstacles in the approach.

No thrombus detected in the LAA.

Morphology: chicken wing/cactus/windsock/cauliflower type with 1/2/3/4 lobe(s).

Dimensions: External anatomical orifice: ... × ... mm; Landing zone: ... × ... mm; Maximum depth: ... mm, Direct depth: ... mm;

Suggested devices: Amulet size ... mm or Watchman-FLX size mm

Other:

Signature

Recommendations	Class (A)	Level (B)	References (C)
ECG-gated CT after intra-venous administration of iodinated contrast material is recommended for feasibility assessment and pre-procedural device selection accuracy for LAAC device implantation	I	B	32, 33, 34, 35, 37
ECG-gated CT after intra-venous administration of iodinated contrast material should be considered for an intra-atrial appendage measurements	IIa	C	28, 30, 31
ECG-gated CT after intra-venous administration of iodinated contrast material with arterial and delayed imaging scan is recommended to detect an intra-atrial appendage thrombus	I	B	43, 44
Cardiac MRI should be considered for intra intra-atrial appendage thrombus detection as an alternative to ECG-gated CT	IIa	B	40
ECG-gated CT after intra-venous administration of iodinated contrast material is recommended after LAAC placement follow-up	I	B	67, 68, 69, 70

A class of recommendations (as reported in ESC guidelines)

B Level of evidence (as reported in ESC guidelines)

C reference(s) supporting recommendations