Multimodality imaging in preoperative assessment of left atrial appendage transcatheter occlusion with the Amplatzer Cardiac Plug

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Aims
Percutaneous left atrial appendage occlusion (LAAO) with the Amplatzer Cardiac Plug (ACP) emerged as a valid alternative in patients with a formal contraindication to oral anticoagulant therapy. Transoesophageal echocardiography (TEE), cardiac computed tomography angiography (CCTA), intracardiac echocardiography (ICE), and conventional cardiac angiography (CCA) are used to evaluate LAA diameters. The aim of our study was to compare pre- and intraprocedural imaging techniques in determining the correct selection of the device size, with a retrospective evaluation of the results obtained at post-procedural CCTA follow-up.

Methods and results
Between September 2009 and July 2013, 66 consecutive patients underwent to LAAO with the ACP at our institution. Preoperative LAA evaluation was realized with TEE, CCTA, ICE, and CCA. Fifty-eight (58) patients underwent to post-procedural CCTA to confirm the LAA complete exclusion, the number and extent of the residual leaks, and the positioning of the device. LAA diameters measured by CCTA correlate with the diameters obtained with CCA and ICE, but they are sized slightly larger than the others. TEE has a lower correlation with every other imaging method and a likely tendency to underestimate. The distribution of the leaks and the positioning of the device in post-procedural CCTA show no substantial differences between the devices used greater or equal to the one selected with CCTA in terms of LAA exclusion.

Conclusion
The sizing of the device decided using CCTA in the phase of maximum LAA expansion reduces the risk of high-flow leaks and device malposition due to undersizing.

Keywords
Percutaneous left atrial appendage occlusion • Amplatzer Cardiac Plug • Transoesophageal echocardiography • Cardiac computed tomography angiography • Intracardiac echocardiography • Conventional cardiac angiography

Introduction
Atrial fibrillation (AF), one of the most common cardiac arrhythmias, is associated with 15–20% of all ischaemic strokes.1 Recent studies have shown that, in non-valvular atrial fibrillation (NVAF), 90% of cardiac thrombi are located in the left atrial appendage (LAA).2 LAA occlusion (LAAO) has emerged as a valid alternative in patients with a formal contraindication to oral anticoagulant (OAC) therapy.3 The most widely used devices are the Watchman (Boston Scientific, MN, USA) and the Amplatzer Cardiac Plug (ACP, St Jude Medical, MN, USA). As shown in PROTECT AF, LAAO with the Watchman device was non-inferior to warfarin treatment for all the primary endpoints (cardiovascular death, stroke, and systemic embolization).4 Favourable results, emerging from registries, have also been published for the ACP.5–9 Percutaneous LAAO is now included in the updated ESC guidelines for AF (Class IIb, Level B).3

Anatomical knowledge of LAA morphology is particularly important for pre-procedural planning. In fact, the selection of appropriate device size for implantation is a major factor for a successful intervention. Accurate measurements of the LAA are critical for the sizing of these devices, and current protocols typically use transoesophageal echocardiography (TEE). Invasive imaging modalities such as TEE or intracardiac echocardiography (ICE) and conventional cardiac angiography (CCA) have certain obvious advantages...
over three-dimensional (3D) non-invasive techniques, such as mul-
tidetector computed tomography (MDCT), due to their ability to
give real-time images, which are very helpful in the catheterization
laboratory. However, 3D techniques may provide additional quali-
tative and quantitative information not otherwise available, such as
high spatial resolution and a detailed 3D and four-dimensional (4D)
assessment of intracardiac structures. Thanks to these advantages
the MDCT is gradually gaining ground in clinical practice in pre-
and postoperative evaluation of LAAO through cardiac computed
tomography angiography (CCTA).

The size selection is not a simple issue, due to the high variability in
the anatomical shape of the LAAs and to the variable information
that different imaging techniques provide for the diameter measure-
ment. In recent studies, a device size different from the one actually
needed had been preselected in a percentage of cases variable
from 17 to 24%.

Although the available imaging techniques are of good value, the
data obtained using different methods may not match, thereby poten-
tially not facilitating the task of choosing the correct size. The main
two measures used to choose the correct size of the occluder
deVICES are the diameters of the LAA ‘ostium’ (OS) for the selection
of the Watchman device, and ‘landing zone’ (LZ) for the selection
of the ACP device, through consultation of the manufacturers’ sizing
charts.

The aim of our study was to compare the pre- and intraprocedural
imaging techniques in patients with NVAF in determining the correct
selection of the device size for LAAO, with a retrospective evaluation
of the results obtained at post-procedural CCTA.

Methods

Study design

In this retrospective single-centre study, 66 consecutive patients under-
went preoperative planning of LAAO between September 2009 and July
2013. All the patients had NVAF with contraindication to OAC therapy
(Chads2Vasc 4.35 ± 1.26; Has-Bled 3.51 ± 1.04; mean age 78 ± 6
years). The procedure was performed with the Amplatz Cardiac Plug
device. Post-procedural CCTA was performed on 58 of 66 patients to
assess LAAO outcome.

Written informed consent was obtained from all patients, and the
study protocol was approved by the Institutional Ethics Committee.

Preoperative measurements of the LAA were carried out and com-
pared with TEE, CCTA, ICE, and CCA.

At post-procedural examinations, the number and extent of the re-
sidual leaks and the positioning of the device was assessed with CCTA.

Prior to the device implantation, extensive imaging modalities were
performed to determine the LAA OS and LZ diameters, to exclude
LAA thrombosis, and to explore the atrial and appendage anatomy in de-
termining the appropriate device size.

In the ‘pre-procedural phase’, TEE and CCTA were used for the
correct measurement of the LAA (OS and LZ), to define the size and
the shape of the LAA as well as to rule out the presence of thrombi.

TEE sizing

TEE was performed with the patient under conscious sedation (e.g. mid-
azolam 2–5 mg) documenting the absence of thrombi within the LAA,

determining the OS and LZ diameters, shape, number of lobes, location,
working length in the LAA, and pectinate features. Two-dimensional (2D)
TEE measurements were obtained by a mid-oesophageal window with
three projections: at ∼45°, 90°, and 135°; the final LZ diameters were
calculated from the average of the three results. The measure performed
at the level of the OS was taken from the left circumflex artery to the tip of
the left upper pulmonary vein and at the level of the LZ 1 cm distal to the
OS (Figure 1A).

CCTA scan parameters

Both pre- and post-procedural CCTA scans were performed with the
same protocol. The examinations were performed by using a 64-
or 320-detector scanner, with a multiphasic acquisition, iodinated contrast
medium (iopromide, Ultravist 370, Bayer SpA, Germany, 70–90 mL) was
administered through an antecubital vein (flow rate: 5 mL/s), followed by
50 mL of saline chaser bolus (sodium chloride 0.9%), administered at the
same flow rate. The dose modulation was used when possible. A first
angiographic acquisition was acquired with retrospective ECG-gating.
A second prospective scan of 4–8 cm (40% R–R), targeted at the LAA,
was performed after 40 s. After ECG editing (when necessary), axial
images were reconstructed with the following parameters: ‘best-phase’
of the R–R interval (mid-to-late diastolic phase) and 75% with slice

Figure 1 (A) TEE image showing LAA OS and LZ. (B) ICE image showing LAA OS and LZ.
thickness 0.5 mm, increment 0.25 mm; 0–90% of the RR interval at 10%
increments (slice thickness 1 mm and increment 1 mm) to evaluate
cardiac morphological and functional changes.

CCTA sizing

The LAA was evaluated with CCTA identifying first the phase of
maximum LAA expansion and then the correct OS and LZ planes with
multiplanar reconstruction (MPR) images.

From the axial acquisition images, a two-chamber long-axis projection
was obtained showing the long axis of the left ventricle as well as the left
appendage. From the latter, placing the cross-sectional axis at the level of
the base of the LAA, rotating it to align with both the ligament of Marshall
and the circumflex artery, a third projection was identified where
the LAA OS was viewable (Figure 2A and B). This oval image, limited by
the ligament of Marshall and circumflex artery, allowed to determine
the morphology and the size of LAA OS.

The LZ plane was detected as a plane between a point 10 mm distal to
the centre of the OS on the midline and the circumflex artery, perpen-
dicular to the long axis of LAA neck (Figure 2B).

To evaluate interobserver variability with CCTA, two blind operators
measured the mean diameter between the maximum diameter and its
orthogonal \(d_M\) and the diameter taken from the area \(d_A\) in a subgroup
of patients.

The diameter taken from the area \(d_A\) was then used as CCTA diameter.

ICE sizing

All implantation procedures were performed with ICE monitoring.

The ICE probe was positioned in the right atrium (RA) or in the coron-
ary sinus (CS). The ICE catheter, placed within the RA, allowed the visu-
ization of the left atrial anatomy, as well as the OS and LZ of the LAA.

ICE was also used to assess the diameter of the LAA by measuring the
transverse diameter 10 mm below the OS (Figure 1B). These measure-
ments were compared with those previously obtained by TEE and with
those chosen by angiography measured by a different operator.

CCA sizing

Left atrium and appendage angiography were performed, and the OS
and LZ diameters were measured using two different projections [right
anterior oblique (RAO) 40° cranial (CRA) 20° and RAO 40° caudal
(CAU) 20°]. As for ICE, the LZ was measured with a transverse diameter
10 mm below the OS. The largest diameters obtained were used as CCA
diameters (Figure 3).

Figure 2  CCTA images showing LAA OS and LZ in the two-chamber long-axis view (A) and oblique projection showing the oval image of the LZ (B).

Figure 3  CCA image showing LAA LZ (A) RAO 40° CRA 20° and (B) RAO 40° CAU 20°.
The occluder device size was selected using CCA measures keeping into account the other techniques.

**Post-procedural CCTA dataset analysis**

Post-procedural CT was performed at 5.2 ± 4.6 months in 58 patients. On post-procedural datasets, complete exclusion of the LAA or the presence of any leak was evaluated. Regarding the presence of leaks, a semi-quantitative CCTA classification was used:

(i) **No leak (NL):** absence of LAA opacification in the delayed phase (Figure 4A).
(ii) **High-flow leak (HFL):** opacification of more than one-third of the appendage in the arterial phase (Figure 4B).
(iii) **Low-flow leak (LFL):** appendage opacification in the venous phase/opacification of less than one-third of the appendage in the arterial phase (Figure 4C and D).

In addition, the correct positioning of device, the possible angle of the device relative to the plane of the LZ and the morphology assumed by the lobe were evaluated.

To determine the correct positioning of the device the following criteria were used:

(i) **Optimal placement (OP):** lobe of the device placed at the level of the LZ (Figure 5A).
(ii) **Angled placement (AP):** lobe of the device placed at the level of the LZ with its axis perpendicular to the lobe diverging from the plane of the LZs (Figure 5B).
(iii) **Suboptimal placement (SOP):** lobe of the device with distal positioning to the LZ (Figure 5C).

Finally, regarding the morphology of the lobe, the same classification used by Park was used. The lobes of the devices were divided into three classes, depending on the form:

(i) **‘Strawberry’:** excessive deformation of the lobe (Figure 6A).
(ii) **‘Square’:** low deformation of the lobe (Figure 6B).
(iii) **‘Tire’:** optimal deformation of the lobe (Figure 6C).

**Role of CCTA in the choice of the device**

On the basis of the comparison between the size of the device used for LAAO (u-dev), selected from all data available from TEE, ICE, and CCA imaging techniques, and the size of the device that would have been used through the appropriate sizing chart (Table 1) only based on measurements obtained with CCTA (ct-dev), three subgroups were identified: u-dev=ct-dev, u-dev<ct-dev. The distribution of the leaks, the correct positioning of the device, and the angulation of the lobe were evaluated in the three subgroups.

![Figure 4](image-url) **Figure 4** ‘Leak classification with LAA’: (A) absence of leak (NL): no opacification of LAA lumen is visible in the venous phase; (B) HFL: opacification is well visible in the arterious phase; and (C and D) LFL: LAA opacification is visible only in the venous phase (D).
Continuous variables are expressed as mean (± SD). The variability of the diameters of the LZ measured with TEE, CCTA, ICE, and CCA techniques was assessed with Pearson’s \( r \) test. Differences between groups in the distribution of leaks, positioning of the device, and angulation of the lobe were compared using a Likelihood ratio test. Significance was set at \( P < 0.01 \). ROC analysis was performed for each method to evaluate the predictive value of the difference between the imaging-derived size and the device size used (\( D \)) for post-procedural leaks.

**Results**

LAA filling defects were evidenced in the angiographic phase in 29 patients. The delayed venous phase excluded the presence of thrombosis in all cases.

The sizing of the LAA with CCTA was performed in all 66 pre-procedural datasets. Measures with other imaging techniques were

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**Table 1**  
Amplatzer Cardiac Plug sizing chart

<table>
<thead>
<tr>
<th>Maximum LZ width (mm)</th>
<th>Disc diameter (mm)</th>
<th>Lobe diameter (mm)</th>
<th>Recommended sheath size (Fr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.6–14.5</td>
<td>20</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>14.6–16.5</td>
<td>22</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>16.6–18.5</td>
<td>24</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>18.6–20.5</td>
<td>26</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>20.6–22.5</td>
<td>30</td>
<td>24</td>
<td>13</td>
</tr>
<tr>
<td>22.6–24.5</td>
<td>32</td>
<td>26</td>
<td>13</td>
</tr>
<tr>
<td>24.6–26.5</td>
<td>34</td>
<td>28</td>
<td>13</td>
</tr>
<tr>
<td>26.6–28.5</td>
<td>36</td>
<td>30</td>
<td>13</td>
</tr>
</tbody>
</table>

The size of the device is chosen on the basis of the LZ diameter, with an oversizing variable from 1.4 to 3.5 mm to ensure a stable positioning of the lobe.
available with TEE in 54 cases, with CCA in 57 cases, and with ICE in 40 cases.

The diameters of the LZ were collected with all imaging modalities in 34 cases. The average values obtained are presented in Table 2.

The interobserver correlation between \( d_A \) and \( d_M \) (Figure 7) was higher for \( d_A \) (\( r = 0.98 \) vs. \( r = 0.93 \)).

The agreement between the device suggested by TEE, CCTA, ICE, CCA, and the device used was calculated (Table 3). The operators showed a tendency to be more confident with CCA measures (agreement of 50%).

The Pearson’s correlation coefficient (PCC) between the measures of the LZ with the different methods (Figure 8) is:

(i) \( r = 0.756 \) between CCTA and CCA (\( P < 0.01 \)—Figure 8A);
(ii) \( r = 0.712 \) between CCTA and ICE (\( P < 0.01 \)—Figure 8B);
(iii) \( r = 0.571 \) between CCTA and TEE (\( P < 0.01 \)—Figure 8C);
(iv) \( r = 0.823 \) between CCA and ICE (\( P < 0.01 \)—Figure 8D);
(v) \( r = 0.595 \) between CCA and TEE (\( P < 0.01 \)—Figure 8E);
(vi) \( r = 0.502 \) between ICE and TEE (\( P < 0.01 \)—Figure 8F).

In 58 post-procedural CCTA datasets under assessment, the distribution of the leaks and the positioning of the device in the three subgroups, u-dev < ct-dev (23), u-dev = ct-dev (20), and u-dev > ct-dev (15), are summarized, respectively, in Tables 4 and 5.
The distribution of the lobe morphology in 28 cases of OP devices is summarized in Table 6. There are no significant differences between u-dev > ct-dev and u-dev = ct-dev in the frequency of leaks and positioning of the device. There is a significant difference between u-dev / ct-dev and u-dev, ct-dev for the distribution of leaks (HFL: 27.9 vs. 66.7%; \( P < 0.01 \)), for an SOP of the device (SOP: 20.9 vs. 53.3%), and for angled device (AP: 25.6 vs. 13.3%; \( P < 0.01 \)).

ROC analysis results performed in 31 patients for the predictive value of post-procedural leaks (Figure 9):

(i) \(-\Delta\text{CT}: \text{area under the curve: 70.24\% (95\% CI: 48.56–91.92\%)}.\)

(ii) \(-\Delta\text{ICE}: \text{area under the curve: 71.43\% (95\% CI: 90.37–52.49\%)}.\)

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**Table 3** Agreement between the suggested device by the imaging techniques and the used device

<table>
<thead>
<tr>
<th>Method</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCTA</td>
<td>11</td>
<td>32.40</td>
</tr>
<tr>
<td>ICE</td>
<td>9</td>
<td>26.50</td>
</tr>
<tr>
<td>CCA</td>
<td>17</td>
<td>50</td>
</tr>
<tr>
<td>TEE</td>
<td>2</td>
<td>5.90</td>
</tr>
</tbody>
</table>

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Figure 8: ‘Scatter plots’—Pearson’s correlation between imaging methods (\( P < 0.01 \)) on measurements of the LZ: (A) CCTA–CCA (\( r = 0.756 \)); (B) CCTA–ICE (\( r = 0.712 \)); (C) CCTA–TEE (\( r = 0.571 \)); (D) CCA–ICE (\( r = 0.823 \)); (E) CCA–TEE (\( r = 0.595 \)); and (F) ICE–TEE (\( r = 0.502 \)).
Multimodality imaging approach to LAA occlusion with ACP

Table 4  Distribution of the leaks in post-procedural CCTA datasets

<table>
<thead>
<tr>
<th>Leak distribution</th>
<th>u-dev&gt;ct-dev</th>
<th>u-dev=ct-dev</th>
<th>u-dev&lt;ct-dev</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL</td>
<td>7</td>
<td>7</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>LFL</td>
<td>9</td>
<td>8</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>HFL</td>
<td>7</td>
<td>5</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>20</td>
<td>15</td>
<td>58</td>
</tr>
</tbody>
</table>

The distribution of the high-flow leaks (HFL), low-flow leaks (LFL), and absence of leak (NL) was researched in three different groups where the device implanted (u-dev) was bigger, equal, or smaller than the device suggested by CCTA measurements (ct-dev).

Table 5  Distribution of the device positioning in post-procedural CCTA datasets

<table>
<thead>
<tr>
<th>Device position</th>
<th>u-dev&gt;ct-dev</th>
<th>u-dev=ct-dev</th>
<th>u-dev&lt;ct-dev</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP</td>
<td>13</td>
<td>10</td>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>SOP</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>AP</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>20</td>
<td>15</td>
<td>58</td>
</tr>
</tbody>
</table>

The distribution of optimal placed (OP), angled placed (AP), and suboptimal placed (SOP) devices was researched in three different groups where the u-dev was bigger, equal, or smaller than the ct-dev.

Table 6  Distribution of the device morphology

<table>
<thead>
<tr>
<th>Morphology of the lobe</th>
<th>u-dev&gt;ct-dev</th>
<th>u-dev=ct-dev</th>
<th>u-dev&lt;ct-dev</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squared</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Tire</td>
<td>10</td>
<td>9</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Strawberry</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
<td>10</td>
<td>5</td>
<td>28</td>
</tr>
</tbody>
</table>

The distribution of lobe morphology on 28 optimal positioned (OP) devices was researched in three different groups where the u-dev was bigger, equal, or smaller than the ct-dev.

(iii) $-\Delta$CCA: area under the curve: 62.8% (95% CI: 36.39–89.2%).
(iv) $-\Delta$TTE: area under the curve: 54.17% (95% CI: 28.81–79.52%).

A moderate accuracy to predict the leak is evident both with CT and with ICE. However, the small size of the sample requires further investigation.

Discussion

Methods correlation

There is a good correlation between CCTA and both ICE and CCA measures; these last two methods have the highest inter-method correlation; however, it is necessary to take into account a possible bias due to the fact that both measures are taken in the catheterization laboratory during the procedure, with a possible mutual influence of operators. TEE seems to have a lower correlation with all the other methods.

From the average of the diameters of the 34 selected cases, it is shown that TEE is the method with the smallest average diameter, with a likely tendency to underestimate, whereas on the other hand, CCTA is the method with the greatest average diameter.

ICE and CCA are in an intermediate position, with the highest inter-method correlation. From these data, a tendency to overestimate of the CCTA may be assumed. However, unlike the other methods, in the CCTA datasets, the phase of maximum LAA expansion was sought, and this justifies, at least in part, the higher average values of the diameters measured. Furthermore, given the ellipsoid nature of OS and LZ lumen, the sizing of LAA using a 3D method should provide greater accuracy than the 2D methods, which could significantly underestimate the size if the imaging plane is not oriented to the largest diameter (Figures 10 and 11).

Role of CCTA in the choice of the device

By analysing the positioning of the device in the post-procedural CCTA, some observations can be expressed:

(i) the positioning of the lobe of the device distal to the LZ (SOP) implies an inability to anchor the same and therefore an undersizing of the device:
(ii) an angulated position of the lobe at the level of the LZ (AP) could be due either to an oversizing of the device or to a procedural difficulty due to the anatomy and the angle at which the catheter is positioned in the LAA, an angle that may limit the optimal positioning of the lobe; and

(iii) regarding the OP device, maintaining into account the morphologies of the lobe already described by Park,\textsuperscript{13} we can consider a 'squared' lobe morphology as a sign of undersizing, a 'tired' lobe morphology as an optimal sized lobe, and a 'strawberry' lobe morphology as a sign of excessive oversizing.

The $u$-$dev$$<$$ct$-$dev$ group deviates significantly from the other two groups both for the distribution of leak (HFL: 66.7 vs. 30.4% of $u$-$dev$$>$$ct$-$dev$ and 25% of $u$-$dev$$=ct$-$dev$) and the number of SOP devices (53.3 vs. 17.4% of $u$-$dev$$>ct$-$dev$ and 25% of $u$-$dev$$=ct$-$dev$), which are positioned distal to the LZ. Regarding the lobe morphology of the OP, non-angled devices and a 'squared' lobe morphology were detected in 20% of $u$-$dev$$<$$ct$-$dev$ vs. 8.7% of $u$-$dev$$=ct$-$dev$ and 5% of $u$-$dev$$=ct$-$dev$.

Both the SOP device and 'square' lobe morphology can be considered signs of an undersizing of the device. Analysing the overall device with signs of undersizing (SOP and 'square' lobe) in the three groups, there is a 73.3% of $u$-$dev$$<ct$-$dev$ vs. 26.1% of $u$-$dev$$=ct$-$dev$ and 30% of $u$-$dev$$=ct$-$dev$.

The absence of significant differences between $u$-$dev$$>$$ct$-$dev$ and $u$-$dev$$=ct$-$dev$ may be interpreted in this context as a degree of tolerance of the oversizing of the device, which would not affect the final outcome of the procedure. The only device with sure signs of excessive oversizing ('strawberry' lobe morphology) is located in the $u$-$dev$$=ct$-$dev$ group, and is also associated with LFL. In this perspective, it should be kept in mind that the same developer, on the basis of the experience with ACP 1, recommends an increased oversizing with the Amulet device (from 1.5–3 mm of oversizing with ACP 1 to 3–6 mm of oversizing with ACP 2).

In view of these considerations, it is therefore reasonable to assume that a choice of the size of the device driven by pre-procedural CCTA would greatly reduce the HFL encountered in this series.

**Comparison with the literature**

According to early clinical experiences with LAAO, an adequate device size tends to be 20–40% larger in diameter than predicted
by TEE.\textsuperscript{14} This finding reinforces the hypothesis given by our experience of a tendency of TEE to underestimate LAA measurements.

Regarding the comparison between invasive imaging methods, inter-method correlation of TEE, ICE, and CCA has been evaluated in a dual-centre study by Berti et al.\textsuperscript{15} In a comparison on LZ diameters measured using the three methods on 51 patients, the correlation found with the PCC was $r = 0.94$ between CCA and ICE, and $r = 0.72$ between TEE and ICE. The patients evaluated in our study are included in the afore-mentioned dual-centre study population, and the different $r$-values between ICE and TEE at the level of the LZ result from the different time of the enrolment and operator confidence with these imaging methods.

Few studies reported in the literature evaluated the correlation between CCTA and the invasive imaging techniques; moreover, the methods of LAA sizing with CCTA datasets were different, and an interpretation of results is difficult. The three main methods described in literature are the measure of diameters with 2D-MPR on standard planes (‘axial’, ‘coronal’, and ‘sagittal planes’), 2D-MPR on oblique plans using a plan perpendicular to the main axis of OS/LZ, and volume rendering (VR). These three methods have been analysed in a study by Wang et al.\textsuperscript{16} on 612 patients. According to their data, the 2D oblique method was better in reproducibility than the other methods.

Budge et al.\textsuperscript{17} compared LAA OS measures obtained with CCTA, on 2D standard MPR and VR, and with TEE in 55 patients. PCC was $r = 0.67$ between 2D standard MPR CCTA measure and TEE, $r = 0.49$ between 3D VR CCTA measure and TEE, and $r = 0.47$ between 2D standard MPR and 3D VR CCTA measure. Only in one case out of 55 was there agreement between the three methods on the choice of device size.

Lopez-Minguez et al. compared LAA OS measures obtained with CCA, TEE, and MDCT (acquisition scan in the angiographic phase without ECG-gating). Measures on MDCT were made with 3D-VR (on a superior—inferior and anterior—posterior axis). The agreement of imaging techniques on the device size was valued. Agreement on the choice of the device was 21.6% between the

\textbf{Figure 10} ‘Orientation of the angiographic projections on CCTA MPR planes: RAO 40° CRA 20°’—angiographic projection represented on 3D VR (D); orientation of the LAA on the four-chamber axial view (A), two-chamber long-axis view (B), and two-chamber short-axis view (C). The diameter measured in this angiographic projection corresponds to the yellow line on the four-chamber view and diverges from the larger diameter of the LAA oval lumen.
three methods, 45.9% between TEE and MDCT, 35.1% between CCA and CCTA, and 24.3% between TEE and CCA. PCC was: $r = 0.87$ between CCA and TEE, and $r = 0.77$ between MDCT (superior—inferior diameter) and CCA. The superior—inferior diameter by MDCT showed the highest percentage of agreement with the appropriate device size (75%), with a tendency to overestimate diameters in the cases of disagreement, while in the cases of disagreement between the 2D methods TEE had a tendency to equally over and underestimate diameters, while CCA had a tendency to underestimate.

Blendea et al.\textsuperscript{18} compared ICE and MDCT/MR measurements of OS on 21 patients. ICE measurements were made in the CS, in the middle RA, and in the left atrium. The inter-method correlation between ICE and 3D methods was related to the location of the probe: PCC was high with the probe in the left atrium ($r = 0.74$), lower with the probe in the CS ($r = 0.37$), and in the RA ($r = 0.41$).

Finally, Krishnaswamy et al.,\textsuperscript{19} in a study on LAA measurements with CCTA (2D oblique MPR) and TEE in a population of 22 patients, found low correlation between the two methods.

**Limitations of the study**

There is an absence of a clear ‘gold standard’ for sizing the LAA because even direct measurements, such as during surgery or post-mortem analysis, are likely to underestimate true in vivo LAA size. Starting from this assumption, it was not possible to determine which method could provide more precise LAA diameters. The absence of leaks has been taken into analysis as a possible indicator of LAAO success and therefore of correct selection of the device. However, the angle between the fossa ovalis and LAA and the appendage morphology, such as the neck length and the number of lobes, are other possible parameters that may influence the presence of leaks and they are not taken into account in this study.

A 3D TEE technique has not been evaluated in this analysis and future comparisons should be performed.

**Conclusions**

In the evaluation of LAA dimensions in determining the correct device, CCTA identifies the phase of greater LAA expansion and...
provides a good correlation with intraprocedural imaging techniques (CCA and ICE), whereas TEE has a lower correlation with every other imaging method.

From the average of the diameters obtained with the different methods, LAA diameters measured with CCTA are sized slightly larger than the others, whereas TEE has a likely tendency to underestimate the diameters.

Analysing the presence of the distribution of the leaks and the positioning of the device in post-procedural CCTA, there is a substantial difference between the group in which the device used is smaller than the one selected with CT and the groups in which the device used is equal to or greater than the one selected with CT. Further investigations are required to understand the evolution and clinical significance of post-procedural leaks.

In conclusion, the sizing of the left appendage evaluated with CCTA seems to reduce the risk of high-flow leaks and placement problems of the device related to undersizing. The risk of possible over-sizing, which cannot be totally excluded, however, does not seem to interfere with the overall success of the procedure.

CCTA appears to be a practical and concrete method in determining the size of the LAA occluder device to implant and in identifying eventual possible collateral findings.

Conflict of interest: S.B. is a proctor for both St Jude and Edwards Lifesciences. All other authors have reported that they have no conflicts to declare. This retrospective observational study complies with the Declaration of Helsinki. The research protocol has been approved by the locally appointed ethics committee.

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