Imaging investigations in infective endocarditis: Current approach and perspectives

Imagerie de l’endocardite infectieuse : approche actuelle et perspectives

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Summary

Infective endocarditis is a serious disease that needs rapid diagnosis and accurate risk stratification to offer the best therapeutic strategy. Echocardiography plays a key role in the management of the disease but may be limited in some clinical situations. Moreover, this method is insensitive for very early detection of the infection and assessment of therapeutic response because it does not provide imaging at the molecular and cellular levels. Recently, several novel morphological, molecular and hybrid imaging modalities have been investigated in infective endocarditis and offer new perspectives for better management of the disease.

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KEYWORDS
Endocarditis; Imaging; Echocardiography; Computed tomography; Magnetic resonance imaging; Positron emission tomography

Abbreviations: CIED, cardiovascular implantable electronic device; CT, computed tomography; FDG, fluorodeoxyglucose; IE, infective endocarditis; MRI, magnetic resonance imaging; NPV, negative predictive value; PET, positron emission tomography; PPV, positive predictive value; TEE, transoesophageal echocardiography; TTE, transthoracic echocardiography.

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**Résumé** L’endocardite infectieuse est une maladie grave qui nécessite un diagnostic rapide et une stratification du risque précise afin définir la meilleure stratégie thérapeutique. L’échocardiographie joue un rôle clé dans la prise en charge de la maladie mais peut présenter des limites dans certaines situations cliniques. De plus, cette méthode est peu sensible pour la détection très précoces de l’infection ainsi que pour l’évaluation de la réponse thérapeutique car elle ne propose pas une imagerie au niveau cellulaire et moléculaire. Récemment, plusieurs nouvelles modalités d’imagerie morphologique, moléculaire et hybride ont été étudiées dans le domaine de l’endocardite infectieuse et offrent de nouvelles perspectives pour une meilleure prise en charge de la maladie.

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**Imaging investigations in infective endocarditis**

**Infective endocarditis: from pathophysiology to imaging**

Infective endocarditis (IE) is a serious disease associated with poor prognosis despite improvements in medical and surgical therapies [1–4]. IE results in a complex pathogenesis that involves many host-pathogen interactions [5–7]. Indeed, previous endocardial lesions can lead to the exposure of the underlying extracellular matrix proteins, local inflammation and then thrombus formation, which is termed ‘non-bacterial vegetation’. In the case of bacteraemia, valves with pre-existing sterile vegetations or tissues with minimal lesions can be colonized because of strong interactions between the bacteria, platelets and endothelial cells via several bacterial surface proteins or plasma-bridging molecules. This process leads to the recruitment of circulating inflammatory cells and the release of cytokines and procoagulant factors, which contribute to the enlargement of vegetations and the protection of bacterial pathogens from host defences. Ultimately, valvular and perivalvular tissues are destroyed, thus increasing the risk of valve dysfunction, abscess formation and embolization [8]. Moreover, in addition to embolic events, other extracardiac life-threatening complications may occur, such as infectious aneurysms and intracranial and visceral haemorrhages.

Therefore, early and reliable diagnostic and risk stratification strategies are critical to reduce delays to the start of appropriate antimicrobial therapy and to identify patients who require urgent valve surgery. As described in recent international recommendations, echocardiography is a simple accurate method for detecting endocardial damage in IE and helping in risk stratification [1,9]. However, echocardiography studies may be limited in some clinical situations [10–12] and this technique is insensitive for very early detection of infection because it does not provide an imaging assessment of IE at the molecular and cellular levels. Recently, other morphological and molecular imaging strategies have emerged for the detection of endocardial involvement and extracardiac complications.

The aims of this review are to provide an update on the value of echocardiography in the management of IE, to discuss the potential role of other imaging techniques and, finally, to consider the challenges and perspectives in the imaging investigations.

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**Morphological imaging of endocardial damage and its consequences**

**Echocardiography: the main imaging modality**

Echocardiography plays a key role not only in the diagnosis of IE but also in the prognostic assessment and follow-up under therapy and during surgery. Recently, recommendations for the practice of echocardiography in IE have been published, to provide an update on the value and limitations of this technique in IE and to define the optimal use of transthoracic echocardiography (TTE) and transoesophageal echocardiography (TEE) [13].

**Echocardiography for the diagnosis of infective endocarditis**

Although IE may present with several very different initial symptoms, its diagnosis usually relies on the association of clinical, microbiological and morphological criteria, which are included in the modified Duke classification [14]. By detecting several forms of endocardial damage, echocardiography remains an accurate method for providing the major diagnostic criteria of IE. Knowledge of the anatomical features of IE is fundamental in order to better understand, analyse and describe the echocardiographic findings (Table 1). TTE is the initial technique of choice for investigation. A normal scan in low-risk patients provides rapid non-invasive confirmation that the diagnosis is unlikely. Moreover, TTE is better than TEE for the detection of anterior cardiac abscesses and for haemodynamic assessment of valvular dysfunction. Because of its higher sensitivity and specificity, TEE is recommended [1,13] in cases of: negative TTE associated with high clinical suspicion; poor TTE quality; presence of prosthetic valves or intracardiac device; and positive TTE (Fig. 1). In preliminary studies, three-dimensional TEE provided incremental value over two-dimensional TEE in its ability to accurately identify and localize vegetations and to identify complications such as abscesses, perforations and ruptured chordae [15,16] (Fig. 2). Thus, echocardiography must be done rapidly and repeated once a week as soon as it is negative but the condition is suspected.
**Table 1** Anatomical and echocardiographic definitions.

<table>
<thead>
<tr>
<th></th>
<th>Surgery/necropsy</th>
<th>Echocardiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation</td>
<td>Infected mass attached to an endocardial structure or on implanted intracardiac material</td>
<td>Oscillating or non-oscillating intracardiac mass on valve or other endocardial structures, or on implanted intracardiac material</td>
</tr>
<tr>
<td>Abscess</td>
<td>Perivalvular cavity with necrosis and purulent material not communicating with the cardiovascular lumen</td>
<td>Thickened, non-homogeneous perivalvular area with echodense or echolucent appearance</td>
</tr>
<tr>
<td>Pseudoaneurysm</td>
<td>Perivalvular cavity communicating with the cardiovascular lumen</td>
<td>Pulsatile perivalvular echo-free space, with colour Doppler flow detected</td>
</tr>
<tr>
<td>Perforation</td>
<td>Interruption of endocardial tissue continuity</td>
<td>Interruption of endocardial tissue continuity traversed by colour Doppler flow</td>
</tr>
<tr>
<td>Fistula</td>
<td>Communication between two neighbouring cavities through a perforation</td>
<td>Colour Doppler communication between two neighbouring cavities through a perforation</td>
</tr>
<tr>
<td>Valve aneurysm</td>
<td>Saccular outpouching of valvular tissue</td>
<td>Saccular bulging of valvular tissue</td>
</tr>
<tr>
<td>Dehiscence of a</td>
<td>Dehiscence of the prosthesis</td>
<td>Paravalvular regurgitation identified by TTE/TEE, with or without rocking motion of the prosthesis</td>
</tr>
<tr>
<td>prosthetic valve</td>
<td></td>
<td></td>
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</tbody>
</table>

Adapted from Habib et al. [13] with permission.

TEE: transoesophageal echocardiography; TTE: transthoracic echocardiography.

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**Figure 1.** Indications for echocardiography in the diagnosis and assessment of infective endocarditis. IE: infective endocarditis; TTE: transthoracic echocardiography; TEE: transoesophageal echocardiography.

Adapted from Habib et al. [1] with permission.

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Echocardiography for risk stratification and follow-up of infective endocarditis

In addition to its role in diagnosing IE, echocardiography also has major prognostic value in IE in predicting death and complications [17,18]. Heart failure, perivalvular extension and embolic events represent the three most frequent and severe complications of IE. Echocardiography plays a key role in the management of these complications by helping a decision to be made regarding valve surgery and its optimal timing.

Heart failure represents the main indication for valve surgery in IE [19] and the operation is usually indicated in an emerging (within 24 hours) or urgent (within a few days) setting [1,9,20,21]. TEE allows identification of the mechanisms responsible for these complications, such as acute valve regurgitation, valve obstruction or intracardiac fistula. Moreover, TTE may provide criteria of poor haemodynamic tolerance, such as torrential regurgitation, elevated left and right filling pressures, pulmonary arterial pressures and ventricular dysfunction. Even in the absence of clinical congestive signs, the presence of these echocardiographic signs suggests the need for valve surgery because the evolution to heart failure usually is inevitable [1].

Perivalvular extensions are present in around 20% of cases [2] and indicate valve surgery because they expose the patient to risks of: heart failure by the occurrence of fistula or prosthetic valve dehiscence; complete atrioventricular block by interruption of the cardiac conduction system; and persistence of the infection [22–24]. TEE is the technique of choice for the diagnosis of perivalvular extension and its resulting complications but TTE seems better in case of anterior abscess of the aortic annulus [25].

Embolic events are frequent and life-threatening complications of IE, which are symptomatic in around 20–25% of cases [26–29] and silent (only detected by cerebral imaging) in almost 50% of cases [26,27]. These events are factors for poor prognosis, especially in case of involvement of the cerebral circulation bed [29]. Echocardiography, especially TEE, is useful for the evaluation of embolic risk...
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at admission, by providing the maximal length, mobility and location of vegetations. Indeed, large and highly mobile vegetations are associated with a higher risk of embolism [17], especially in the mitral position [30]. This evaluation must be performed very early in the course of IE because the risk of embolic events remains high during the first week after diagnosis and initiation of antibiotics [17,31,32]. Therefore, valve surgery should be performed in an urgent setting when a large vegetation (>10 mm) is present following one or more embolic episodes. In addition, when associated with other known predictors of a complicated course (heart failure, persistent infection under therapy, abscess and prosthetic endocarditis), the presence of a large vegetation (>10 mm) indicates an earlier surgical decision. Finally, the decision to operate in the case of an isolated very large vegetation (>15 mm) is more difficult and must be specific for the individual patient. Surgery may be preferred when a valve repair seems possible, particularly in mitral valve IE [1,33]. Nevertheless, the prediction of embolism remains challenging and should take into account other criteria, such as the type of microorganisms (Staphylococcus aureus) and conditions associated with a prothrombogenic state (atrial fibrillation, diabetes, etc.). Recently, a randomized trial demonstrated that early surgery in patients with large vegetations and significant valve dysfunction significantly reduced the composite endpoint of death from any cause and embolic events by effectively decreasing the risk of systemic embolism compared with conventional therapy [34]. Although this result is of crucial importance, it was limited by the fact that it was obtained in a population with a very low operative risk. Thus, we now have strong evidence that early surgery reduces embolic risk but we need better risk stratification in order to evaluate accurately the benefit-risk ratio of this procedure. Indeed, for a high embolic risk associated with a low or intermediate predicted operative mortality (computed by scoring systems), the benefit of early surgery would be greater.

Intraoperative TEE is mandatory in patients operated on for IE; it provides the surgeon with a final anatomical evaluation of valvular and perivalvular damage, and is particularly useful for assessing the immediate result of conservative surgery, as well as in cases of complex perivalvular repair [35]. Finally, echocardiography must be used for follow-up of patients with IE under antibiotic therapy and after surgery, along with clinical follow-up. The number, type and timing of repeat examinations depend on clinical presentation, type of microorganism and initial echocardiographic findings. After hospital discharge, the main complications include recurrence of infection, heart failure, need for valve surgery and death. Thus, clinical and echocardiographic periodic close follow-up (at 1, 3, 6 and 12 months) is mandatory during the first year after the end of antibiotic treatment [1].
Limitations of echocardiography in infective endocarditis

A negative echocardiogram may be observed in about 15% of cases of IE. The imaging diagnosis may be particularly challenging in some cases, such as with intracardiac devices, valvular prostheses, the presence of pre-existing severe lesions (mitral valve prolapse, degenerative lesions), very small vegetations and abscesses or no vegetation. In addition, the diagnosis may be difficult at the early stage of the disease. Conversely, false diagnosis of IE may occur in other situations: for example, it may be difficult to differentiate between vegetations and thrombi, cusp prolapse, cardiac tumours, myxomatous changes, Lambi’s excrescences or strands. Thus, in some situations, the echocardiogram remains negative or doubtful, even if it is performed by expert hands and after a repeat examination [12,36]. Innovations in the specialty of diagnostic strategy have emerged to resolve these issues through new imaging modalities. Multislice computed tomography (CT) and magnetic resonance imaging (MRI) might help to better identify both anatomical intracardiac damages and extracardiac complications. Positron emission tomography (PET) and other molecular imaging methods might provide imaging of the inflammation and infection at molecular level and will be fused with ‘anatomical’ imaging.

Multislice computed tomography

Recent advances in the temporal and spatial resolution of multislice CT scanners allow high-resolution cardiac imaging. Currently, the major application of multislice CT is in the evaluation of coronary artery disease but it has been used also for heart valve disease, such as aortic stenosis [37] and, more recently, in IE [38–40].

In a small study of 37 consecutive patients with clinically suspected IE, Feuchtnner et al. found good results in detecting IE valvular and perivalvular damage using electrocardiogram (ECG)-gated 64-slice CT or dual-source CT. The diagnostic performance of CT for the detection of evident abnormalities for IE compared with TEE was: sensitivity 97%, specificity 88%, positive predictive value (PPV) 97% and negative predictive value (NPV) 88% on a per-patient basis. In a per valve-based analysis, the diagnostic accuracy for the detection of vegetations and abscesses/pseudoaneurysms compared with surgery was: sensitivity 96%, specificity 97%, PPV 96%, NPV 97% and sensitivity 100%, specificity 100%, PPV 100%, NPV 100%, respectively, without significant differences compared with TEE. Although the small leaflet perforations were missed, CT provided more accurate anatomical information regarding the perivalvular extent of abscesses/pseudoaneurysms than TEE [39]. Gahide et al. found similar results in patients with aortic valve IE [40].

As prosthetic valve IE represents one of the most difficult situations for echocardiographic studies, Fagman et al. recently investigated the role of ECG-gated 64-slice CT in the diagnosis of aortic prosthetic valve IE. In 27 patients, the authors showed that the strength of agreement between ECG-gated CT and TEE was good for abscess and dehiscence, and moderate for vegetation. In comparison with intraoperative findings, CT detected three additional pseudoaneurysms that were unnoticed by TEE. In two of these cases, the pseudoaneurysm was located close to the right coronary cusp, a location that is difficult to investigate by TEE [38].

Thus, this imaging modality offers the possibility to rapidly image the heart and other organs and thus to identify both cardiac lesions and extracardiac complications, such as embolic events, infectious aneurysms, haemorrhages and septic metastases, which can modify the therapeutic strategy (Fig. 3). Moreover, it provides an anatomical assessment of the coronary bed, which is important in the preoperative evaluation [39]. CT seems to be especially useful in case of a negative or inconclusive echocardiographic study. However, contrast products should be used with caution in patients with renal failure or haemodynamic instability because of the risk of worsening renal impairment in combination with antibiotic nephrotoxicity. In some cases, the indications for a CT scan might be limited to the brain and its arteries. Specific recommendations are needed to clearly define the appropriate situations where this modality should be used.

Magnetic resonance imaging

Although multiple case reports on the use of MRI in identifying valvular and perivalvular damage in patients with IE have been published, this imaging modality seems to be of most value in the identification of silent cerebral complications [26–28,41,42]. The role of cerebral MRI in the diagnosis and management of this disease has been defined in some studies, which showed that systematic MRI could detect subclinical cerebrovascular complications in about 50% of patients [26–28].

In a single-centre study, Duval et al. described how the identification of brain damage by cerebral MRI modified their classification and management of 130 patients with suspected or definite endocarditis. In this work, MRI identified cerebral lesions in 82% of cases. Solely on the basis of these MRI results, and excluding microhaemorrhages, the diagnostic classification of 32% of the cases of non-definite endocarditis was upgraded to either definite or possible. Moreover, the therapeutic plans were modified for 18% of patients, including surgical plan modifications for 14% [27]. The same investigators analysed the benefit of the addition of abdominal MRI in these patients; they demonstrated that both cerebral and abdominal MRI findings affected diagnosis, but only cerebral MRI affected clinical management plans [43].

MRI offers the advantages of a non-ionizing imaging modality but is limited by its lower spatial resolution and availability in comparison with current CT scans.

Imaging of infectious aneurysms

Infectious (mycotic) aneurysms result from septic arterial embolism to the intraluminal space or vasa vasorum, or from subsequent spread of infection through the intimal vessels. Because of the involvement of the muscular layer, infectious aneurysms are actually pseudoaneurysms [44]. The intracranial arteries are the most frequent location, with a predilection for the distal branching points of the middle cerebral artery. The reported frequency of infectious aneurysms of 2–4% is probably an underestimation as some are clinically silent [45]. As the clinical
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Figure 3. Cardiac and cerebral computed tomography (CT) scan in a patient with a mitroaortic infective endocarditis. This figure illustrates that the CT scan allows rapid and accurate assessment of structural cardiac damage and extracardiac complications. The electrocardiogram-gated cardiac CT scan (A) shows a calcified aortic valve with a large pseudoaneurysm just below the ostium of the left coronary artery (green arrow) and an 'aneurysm' of the mitral valve anterior leaflet (red arrow). The cerebral CT scan (B) shows, after contrast injection, the suspicion of a mycotic (infectious) aneurysm of the right middle cerebral artery (orange arrow), which was confirmed by three-dimensional reconstruction of the angiography (C,D).

Presentation is highly variable (focal neurological deficit, headache, confusion, seizures) and the prognosis is poor, imaging should be performed to detect infectious aneurysms in any case of IE with neurological symptoms [1]. CT or magnetic resonance (MR) angiography may be used to detect infectious aneurysms with similar sensitivity but no recent large series has been performed to address this issue. A study showed that the sensitivities of CT scanning and MR angiography were 94% and 86%, respectively, for the detection of intracranial non-infectious aneurysms 5 mm or larger but only 57% and 35%, respectively, for aneurysms < 5 mm [46]. Thus, conventional angiography remains the gold standard and should be performed when non-invasive techniques are positive or negative with a remaining suspicion.

Imaging of actors involved in infective endocarditis pathophysiology

Echocardiography, CT and MRI provide morphological imaging without accurate information on the activity of IE. This lack of functional data is a strong limitation, especially when the microbiological investigations are negative and in case of negative or doubtful structural lesions. Moreover, these morphological imaging modalities are insensitive for very early diagnosis and accurate assessment of the response to antibiotic therapy [47]. Hope comes from the imaging of actors involved in IE pathophysiology. The vegetations are composed of microorganisms, inflammatory cells, platelets and fibrin. Currently, as there are major difficulties in radiolabelling microorganisms at the site of infection,
methods of conducting molecular imaging of the host’s reaction have emerged. These methods aimed to detect the inflammation and infection processes. Among them, $^{18}$F-fluorodeoxyglucose ($^{18}$F-FDG) PET/CT is the modality that has been most studied recently in the clinical setting.

$^{18}$F-FDG PTE/CT in infective endocarditis

$^{18}$F-FDG PET/CT is an imaging modality that allows measurement of metabolic activity within an organ, obtained from the emission of positrons following disintegration of the injected radioactive product. As the majority of the malignant cells have high glycolytic activity, this technique is widely used for the diagnosis and follow-up of cancers. Recently, it has been used for the identification of inflammatory and infectious processes because they also result in significant FDG uptake by the inflammatory cells. Thus, $^{18}$F-FDG PET/CT has been used in the detection of vascular prosthetic infections [48,49]. Recently, numerous case reports and a few preliminary studies have shown much promise for this modality in the setting of IE. It was reported in several cases that $^{18}$F-FDG PET/CT was able to detect periprosthetic valve abscesses, while the first TTE and TEE studies were normal or doubtful (Fig. 4) [50–52]. This situation represents almost 30% of cases [12]. Moreover, $^{18}$F-FDG PET/CT is able to reveal the source of infection, which can be a neoplasia (colonic cancer) in some cases. However, for the time being, the role of $^{18}$F-FDG PET/CT has been especially investigated in the detection of peripheral emboli and the diagnosis of cardiovascular implantable electronic device (CIED) infections [53].

In a prospective study including 24 patients with definite IE, $^{18}$F-FDG PET/CT detected a clinically occult embolism or metastatic infection in 28% of cases [50]. Three recent works have investigated the role of $^{18}$F-FDG PET/CT in CIED infections (Table 2).

Bensimhon et al. investigated the diagnostic value of $^{18}$F-FDG PET/CT. The authors analysed 21 patients with suspected CIED infection and 14 controls free of infection. The final diagnosis was obtained either from bacteriological data after device culture or by a 6-month follow-up according to modified Duke’s criteria. Sensitivity, specificity, PPV and NPV were, respectively, 80%, 100%, 100% and 84.6% in the patient-based analysis; they were 100%, 100%, 100% and 100% for boxes but only 60%, 100%, 100% and 73% for leads. None of the control patients was positive for CIED uptake [54].

In another study, Ploux et al. tested the role of $^{18}$F-FDG PET/CT in the management of suspected CIED infections. By including 10 patients with a suspected CIED infection with negative TEE signs, the authors showed that six patients had an increased FDG uptake. As a result of this finding, these patients subsequently underwent complete removal of the implanted material. Cultures of the leads were positive in all six patients, confirming involvement of the leads in the infectious process. In the other four patients, the pacing system was left in place without objective signs of active lead endocarditis during follow-up [55].

Sarrazin et al. have made additional important contributions regarding the utility of $^{18}$F-FDG PET/CT for suspected CIED infection. In a study including 66 patients, they
confirmed the relative good sensitivity (89%) and specificity (86%) of \(^{18}\)F-FDG PET/CT interpreted by a qualitative visual score. Moreover, they provided evidence that inflammation accompanying acute pocket surgery does not result in false positive imaging, thus extending the applicability of this technique to suspected early device infection. The authors also demonstrated the ability to distinguish deep pocket infection, which implies device infection and the necessity for device extraction, from superficial infection, which can be treated with antibiotics alone [56].

Although the preliminary results of \(^{18}\)F-FDG PET/CT in the diagnosis and the management of IE are encouraging, several questions remain. What is its value in native and prosthetic valve IE? Is it cost-effective? What is the impact of prolonged prior antibiotic therapy? What is the impact of hyperglycaemia? More experience, especially with use of the new ECG-gated PET/CT, is necessary before strong recommendations can be made regarding the use of this technique.

Other functional imaging modalities

Gallium-67-, indium-111- and technecium-99m-HMPAO-labelled leucocyte scintigraphy is another option for imaging the infection that has been used in clinical practice [57–61]. Unlike \(^{18}\)F-FDG PET/CT, this method is more specific for infection but is more time-consuming (24 hours) and offers poor image quality. Although this modality showed good performances when vascular prosthetic infection was suspected [62], its value in IE should be demonstrated.

Better knowledge of the host/pathogen interaction offers new perspectives in the field of functional imaging of IE. Indeed, by labelling other actors involved in this unique interaction some investigators have developed novel imaging methods from animal models.

Because vegetations are platelet-fibrin clots in which platelet proaggregant activity is enhanced by bacterial colonization, Rouzet et al. investigated the ability of radio-labelled (Tc-99m) annexin V, to provide in vivo functional imaging of platelet activation in an animal endocarditis model (rabbits and rats). Annexin V is a ligand of phosphatidylserines exposed by activated platelets and apoptotic cells. This experimental study showed that this technique can provide functional imaging of vegetations as well as embolic events [63].

In a mouse model, Panizzi et al. developed a new method for imaging S. aureus IE. Because S. aureus is able to induce blood coagulation via staphylocoagulase, the investigators created a fluorescent prothrombin-based probe that could be activated in vivo by the enzyme. When injected into mice with IE, fluorescence molecular tomography combined with CT revealed the presence of vegetations with a high specificity and a high signal over background. Moreover, they generated a new prothrombin-based probe for PET-CT imaging, which showed similar results. Finally, this innovative

<p>| Table 2 | Diagnostic value of (^{18})F-FDG PET/CT in cardiovascular implantable electronic device infections. |</p>
<table>
<thead>
<tr>
<th>Study</th>
<th>Material</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bensimhon et al. [54]</td>
<td>Leads</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>Ploux et al. [55]</td>
<td>Leads</td>
<td>100</td>
<td>93</td>
</tr>
<tr>
<td>Sarrazin et al. [56]</td>
<td>Pocket + leads</td>
<td>89</td>
<td>86</td>
</tr>
</tbody>
</table>

CT: computed tomography; FDG: fluorodeoxyglucose; PET: positron emission tomography.

<p>| Table 3 | Potential indications for imaging modalities other than echocardiography in infective endocarditis. |</p>
<table>
<thead>
<tr>
<th>Imaging modality</th>
<th>Potential indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerebral CT scan</td>
<td>In all patients (with or without neurological symptoms) at admission, to detect: cerebral infarctions; cerebral haemorrhages; infectious aneurysms</td>
</tr>
<tr>
<td>Abdominal CT scan</td>
<td>In patients with a difficult diagnostic situation or difficult surgical decision, and in patients with uncontrolled infection, to detect: visceral infarctions; visceral abscesses; infectious aneurysms</td>
</tr>
<tr>
<td>Cerebral MRI</td>
<td>Same indications as cerebral CT scan. MRI is preferable when available because it provides better sensitivity for the detection of small cerebral infarctions and haemorrhages without ionizing radiation and injection of nephrotoxic contrast products</td>
</tr>
<tr>
<td>Cerebral angiography</td>
<td>In patients with: cerebral haemorrhages; clinical suspicion of infectious aneurysm but negative CT or MR angiography; presence of infectious aneurysm on CT scan or MR angiogram</td>
</tr>
<tr>
<td>PET/CT scan</td>
<td>Suspicion of prosthetic valve or pacemaker/defibrillator leads endocarditis with negative or doubtful echocardiography</td>
</tr>
</tbody>
</table>

CT: computed tomography; MR: magnetic resonance; MRI: magnetic resonance imaging; PET: positron emission tomography.
method allowed visualization of the response to the antibiotic treatment [64].

Conclusions and perspectives

Imaging of IE remains a diagnostic challenge because echocardiography has several limitations, which can impact on patient prognosis. Novel imaging modalities are emerging and offer hope of better management of the disease and thus a reduction in mortality. Some of these methods provide a better morphological evaluation of the intra- and extracardiac damage; others allow visualization of the inflammation and infection at the molecular level. Although more studies are necessary to clearly define the indications for each method, the new modalities should be included in the diagnostic criteria for IE. The future in imaging of IE will be multimodal (Table 3, Fig. 5).

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References

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