Emerging Technologies in Cardiovascular Imaging

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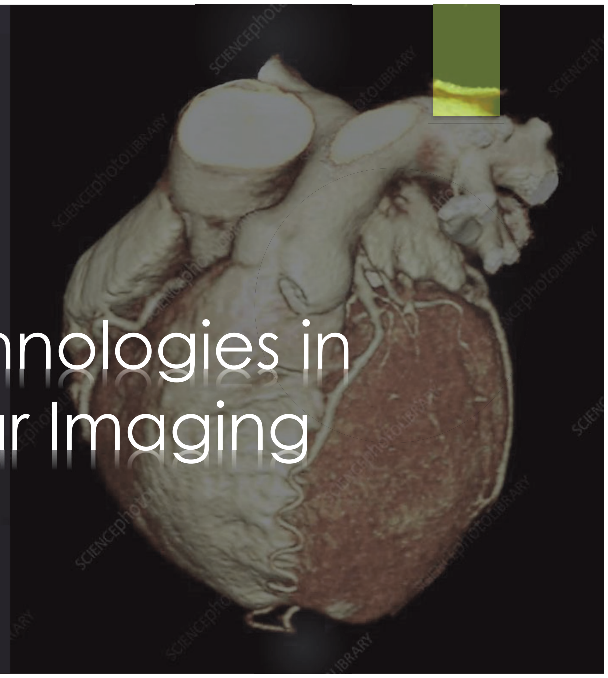
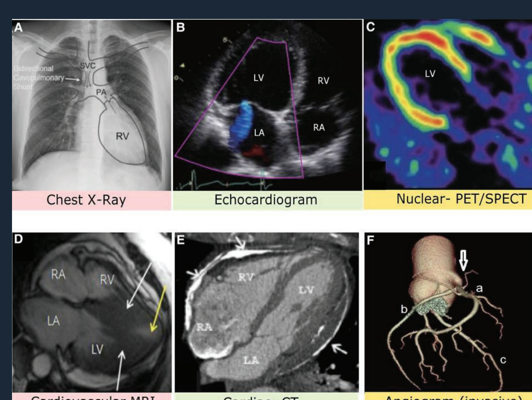


Objectives

- Understand the technical principles and clinical applications of emerging cardiovascular imaging technologies
- Compare the advantages and limitations of photon-counting CT, advanced CMR techniques, 3D/4D echo, and novel PET tracers
- Recognize how artificial intelligence is transforming image acquisition, analysis, and clinical decision support
- Identify cross-cutting themes and future directions in cardiovascular imaging over the next 5-10 years

Why Emerging Technologies Matter

- **Earlier Disease Detection**
  Identify subclinical disease and subtle tissue changes before functional abnormalities develop
- **Improved Risk Stratification**
  More precise characterization of disease severity and prognosis to guide treatment decisions
- **Personalized Treatment**
  Tailored therapeutic approaches based on individual patient's disease phenotype
- **Treatment Response Monitoring**
  Quantitative assessment of therapeutic efficacy with greater sensitivity than conventional methods



Photon-Counting CT: Concept

Technology Principle

Direct conversion of individual X-ray photons to electrical signals, with **energy discrimination** capabilities

Key Differences vs. Conventional CT

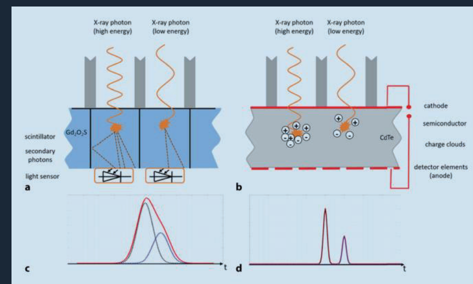
Eliminates electronic noise, provides higher spatial resolution, and enables **spectral information** from a single acquisition

Technical Advantages

Improved signal-to-noise ratio, reduced radiation dose, decreased calcium blooming, and enhanced material differentiation

Cardiovascular Applications

Superior coronary visualization, advanced plaque characterization, and simultaneous **multi-contrast imaging** (e.g., calcium, iodine, soft tissue)



Photon-Counting CT: Clinical Applications

Coronary Artery Visualization

Improved lumen delineation with **reduced calcium blooming**, enabling more accurate stenosis assessment in calcified vessels

Plaque Characterization

Enhanced differentiation of plaque components (lipid, fibrous, calcified) and identification of high-risk features

Myocardial Perfusion

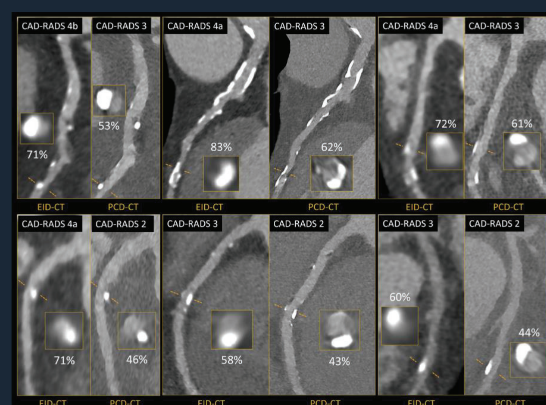
More accurate quantification of myocardial blood flow with improved iodine detection and reduced beam-hardening artifacts

Radiation Dose Reduction

Equivalent or superior image quality at **30-40% lower radiation dose** compared to conventional CT

Clinical Impact

Potential to reduce false-positive findings, unnecessary



Vecsey-Nagy et al, Circ Card Img 2024

CT Perfusion & FFR-CT

CT Myocardial Perfusion

Dynamic imaging during contrast passage to assess myocardial blood flow; can detect ischemia with **comparable accuracy** to nuclear techniques

FFR-CT Concept

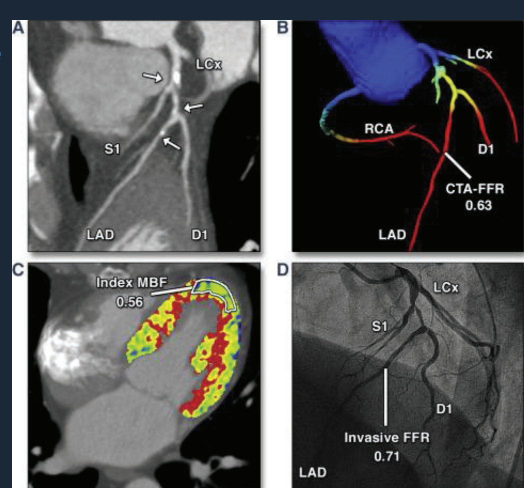
Computational fluid dynamics applied to coronary CT datasets to simulate pressure gradients across stenoses **without invasive measurements**

Diagnostic Performance

Sensitivity 80-90%, specificity 70-80% compared to invasive FFR; negative predictive value >90% for ruling out hemodynamically significant stenosis

Integration with PCCT

Improved image quality from PCCT enhances FFR-CT accuracy; potential for **comprehensive anatomic and functional assessment** in a single scan



Clinical Impact

AI Applications in Cardiac CT

Automated Segmentation

Precise chamber, vessel, and coronary segmentation with accuracy comparable to expert readers but with significantly reduced processing time

Plaque Characterization

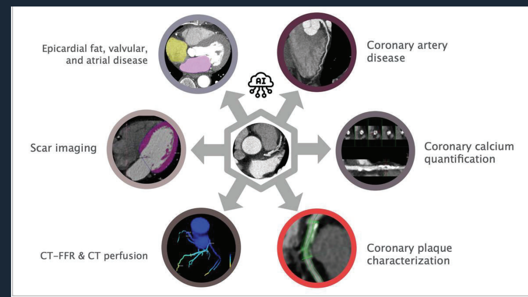
Automated quantification of plaque volume, composition (calcified, non-calcified, mixed), and high-risk features (napkin-ring sign, spotty calcification)

CT-FFR Computation

Machine learning approaches reducing computational time for CT-FFR from hours to minutes, enabling on-site analysis without cloud processing

Structured Reporting

Automated generation of standardized reports with quantitative metrics, risk scores, and comparison to reference ranges and prior studies



Baebler, et al. Front Card Med, 2023

CMR Parametric Mapping: Concept

What is Parametric Mapping?

Quantitative pixel-by-pixel measurement of specific magnetic tissue properties (T1, T2, T2*) displayed as color-coded maps

T1 Mapping

Measures longitudinal relaxation time; sensitive to water content, edema, fibrosis, and protein deposition

T2 Mapping

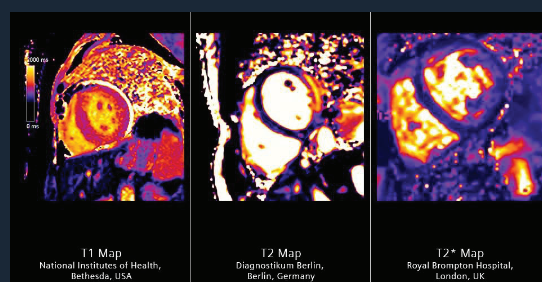
Measures transverse relaxation time; primarily sensitive to water content and edema

Extracellular Volume (ECV)

Derived from pre/post-contrast T1 values; quantifies extracellular space expansion due to fibrosis or amyloid

Advantages Over LGE

Detects **diffuse** myocardial disease processes that may appear normal on conventional LGE imaging



Siemans

CMR Parametric Mapping: Clinical Applications

Myocarditis

Native T1 and T2 mapping detect acute inflammation with higher sensitivity than Lake Louise Criteria; useful for diagnosis and monitoring treatment response

Hypertrophic Cardiomyopathy

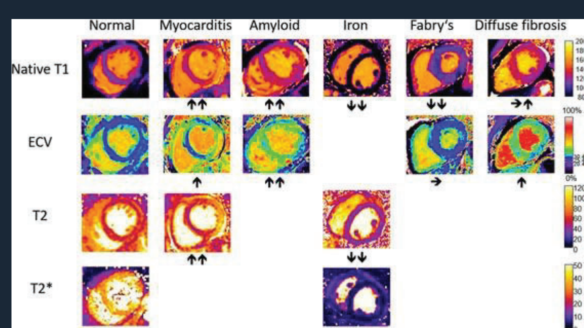
Native T1 and ECV detect diffuse fibrosis beyond areas of LGE; correlate with markers of diastolic dysfunction and arrhythmic risk

Cardiac Amyloidosis

Markedly elevated native T1 and ECV (>40%) are highly specific; can differentiate subtypes and quantify amyloid burden without contrast in renal failure

Iron Overload

T2* mapping provides accurate quantification of myocardial iron content; guides chelation therapy and predicts cardiac complications



Messroghli, et al. JMR 2017

Cardio-Oncology

MR Fingerprinting: Concept

Novel Approach to Quantitative MRI

Generates unique signal "fingerprints" for different tissue types through varied acquisition parameters

Acquisition Method

Uses **pseudorandom** variation of multiple parameters (flip angle, TR, TE) in a single acquisition

Pattern Matching

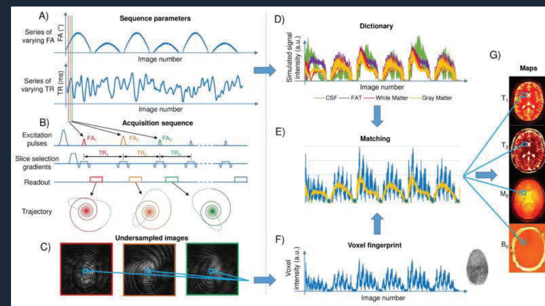
Compares acquired signal evolution to a dictionary of simulated patterns to identify tissue properties

Multiparametric Output

Simultaneously generates multiple quantitative maps (T1, T2, proton density) from a **single efficient scan**

Advantages

Increased efficiency, reduced sensitivity to motion, and improved reproducibility compared to conventional mapping



Panda et al, Curr Opin Biomed Eng 2018

MR Fingerprinting: Future Clinical Potential

Cardiomyopathy Phenotyping

Comprehensive tissue characterization for more precise differentiation between cardiomyopathy subtypes and stages

Myocarditis Assessment

Simultaneous evaluation of edema, inflammation, and early fibrosis with **improved sensitivity** over Lake Louise Criteria

Therapy Monitoring

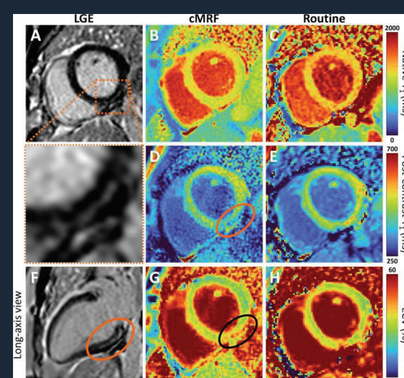
Quantitative tracking of treatment response in inflammatory and infiltrative cardiomyopathies with greater reproducibility

Accelerated Protocols

Potential for **rapid comprehensive exams** with multiparametric tissue characterization in under 15 minutes

Expanded Dictionary Parameters

Future dictionaries may include diffusion, perfusion, and metabolic parameters for even more



T_1 and T_2 maps in a 40 y.o. patient with viral myocarditis and old sub-epicardial scar in the basal infero-lateral and inferior wall. (**A**,**F**) Short- and long-axis late-gadolinium-enhanced (LGE) images showing the presence of the subtle subepicardial scar. (**B**,**C**) Native T_1 maps. The routine T_1 map had slightly higher overall T_1 myocardial values. (**D**,**E**) T_1 maps 20–25 min after contrast agent injection. We can

3D/4D Echo for Structural Interventions

Volumetric Acquisition

Full-volume datasets providing comprehensive spatial relationships and **en-face views** of cardiac structures

Real-Time 3D (4D) Imaging

Dynamic visualization of moving structures throughout the cardiac cycle with improved temporal resolution

Procedural Guidance

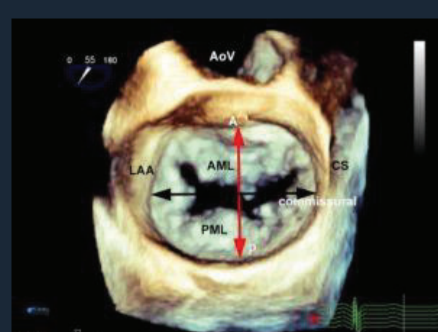
Surgical-view perspectives for transcatheter interventions, including valve repairs, closures, and LAA occlusion

Fusion Imaging

Integration with fluoroscopy for enhanced spatial orientation and reduced radiation exposure during procedures

Quantitative Analysis

Precise measurements of complex 3D structures for pre-procedural planning and post-intervention assessment



Case Example

Clinical Scenario

65-year-old male with severe mitral regurgitation being evaluated for transcatheter edge-to-edge repair (TEER)

3D TEE Findings

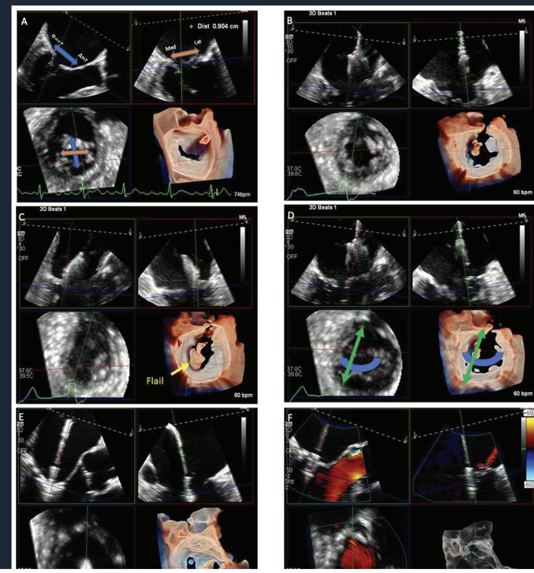
- En-face view confirms P2 flail segment with ruptured chordae
- Precise measurement of flail gap (6mm) and width (10mm)
- Visualization of regurgitant jet origin and direction
- Assessment of adjacent segments for potential clip placement

Procedural Impact

3D guidance enabled precise clip positioning at the center of the regurgitant jet, resulting in reduction from severe to mild regurgitation with a single clip

Key Advantage

En-face view provides **surgical perspective** that cannot be obtained with 2D imaging, improving spatial understanding



AI Protocols for Quantifying Mitral Regurgitation

Automated 3D Vena Contracta Area

AI-driven identification and measurement of the narrowest cross-sectional area of the regurgitant jet with **superior reproducibility**

PISA Automation

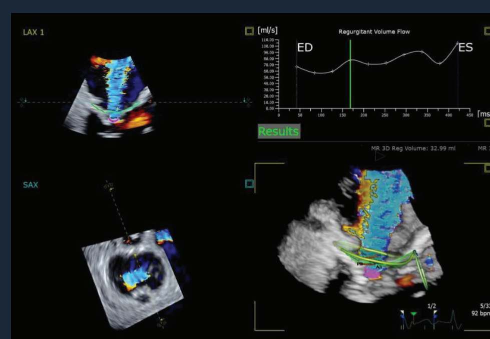
Precise detection of flow convergence region with automated radius measurement and dynamic adjustment for non-hemispheric shapes

Regurgitant Volume Quantification

Direct measurement of regurgitant volume using 3D color Doppler datasets with automated integration of flow across the valve plane

Multi-Parameter Integration

AI algorithms combining multiple parameters (EROA, regurgitant volume, jet characteristics) for comprehensive severity grading



Philips 3DQ

Clinical Validation

Why New PET Tracers? (Perfusion)

Limitations of SPECT

Lower spatial resolution, attenuation artifacts (especially in women and obese patients), and limited ability to quantify absolute myocardial blood flow

Advantages of PET

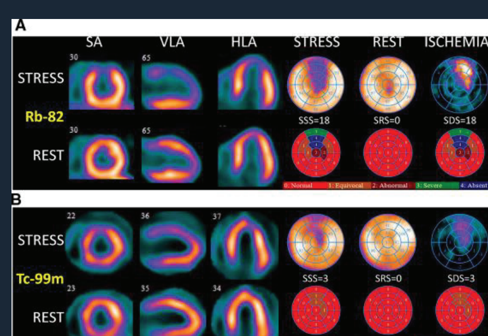
Superior spatial resolution, routine attenuation correction, and ability to **quantify absolute myocardial blood flow** in mL/min/g

Current PET Tracer Limitations

Rb-82 has short half-life (76 seconds) requiring on-site generator; N-13 ammonia requires on-site cyclotron; both limit widespread adoption

Clinical Need

Detection of balanced ischemia and microvascular disease; improved accuracy in women and obese patients; more accessible quantitative perfusion imaging



Ideal Tracer Properties

18F-Flurpiridaz: Mechanism & Logistics

Mechanism of Action

Mitochondrial complex I inhibitor that binds with high affinity to mitochondria-rich cardiomyocytes, reflecting cellular viability and perfusion

Half-Life Advantage

110-minute half-life of F-18 enables **regional distribution** from centralized cyclotrons, unlike Rb-82 (76 seconds) or N-13 ammonia (10 minutes)

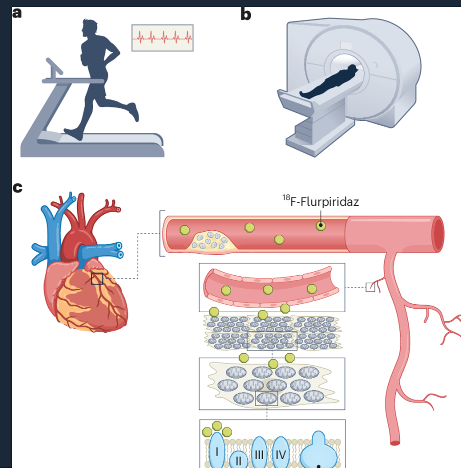
Flow Characteristics

High first-pass extraction (>90%) with minimal roll-off at high flow rates, enabling more accurate quantification of hyperemic flow

Dosimetry

Effective dose of 5-7 mSv for rest/stress protocol, comparable to Rb-82 and lower than many SPECT protocols

Distribution Model



18F-Flurpiridaz: Clinical Performance & Outlook

Phase 3 Trial Results

Superior diagnostic performance vs. SPECT (sensitivity 71.9% vs. 53.7%, specificity 76.2% vs. 73.8%) for detecting ≥50% stenosis by invasive angiography

Special Populations

Particularly improved performance in women (sensitivity 78.8% vs. 43.1%) and obese patients (sensitivity 75.0% vs. 56.7%) compared to SPECT

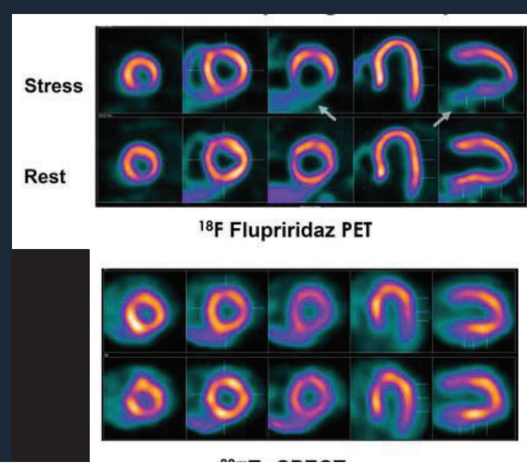
Flow Quantification

Enables absolute myocardial blood flow quantification for detection of **balanced ischemia** and microvascular disease not visible on relative perfusion imaging

Image Quality

Higher spatial resolution (≤2.5mm) and improved target-to-background ratio compared to both SPECT and current PET tracers

Regulatory Timeline



Cross-Cutting Themes

AI-Assisted Workflow

Artificial intelligence now enhances acquisition protocols, image reconstruction, automated segmentation, and structured reporting across all modalities

Quantification Revolution

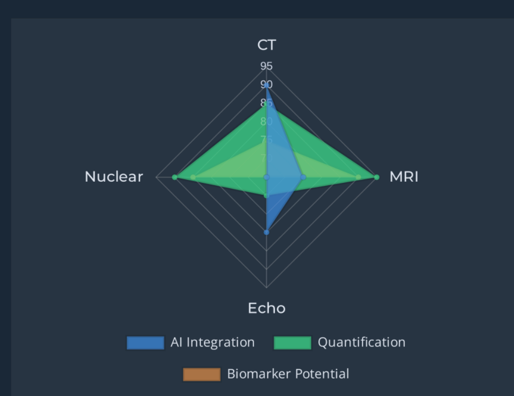
Transition from qualitative, subjective interpretation to reproducible, standardized quantitative metrics with reduced inter-observer variability

Imaging as Biomarker

Advanced imaging parameters serve as surrogate endpoints for clinical trials and precision medicine approaches to guide and monitor therapy

Multimodality Integration

Fusion of complementary imaging techniques provides comprehensive assessment of anatomy, function, and biology in a single patient-centric view



Future Outlook (5–10 Years)

Advanced CT Integration

PCCT becomes mainstream for coronary work-ups with integrated CT perfusion and CT-FFR in a single comprehensive exam

Standardized MR Mapping

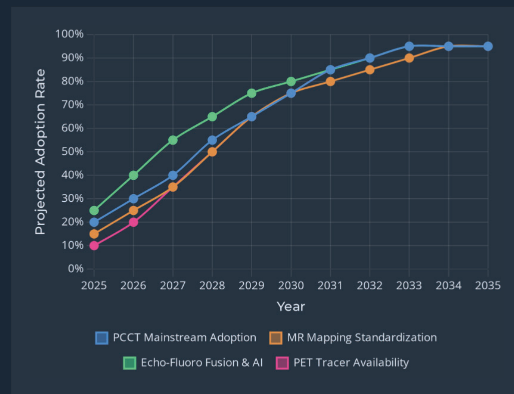
MR mapping and fingerprinting protocols standardized acrossvendors and centers with established reference ranges for major cardiomyopathies

Integrated Interventional Imaging

Echo-fluoro fusion and AI-driven valve assessment embedded in structural heart programs, reducing procedure times by 30-40%

Democratized Nuclear Cardiology

PET with next-generation tracers widely available in community settings, replacing SPECT as the standard for myocardial perfusion imaging



Take-Home Messages

From Anatomy to Physiology
Emerging technologies are shifting focus from purely anatomical assessment to integrated physiological characterization, enabling more comprehensive disease evaluation

Quantification is Key
Quantitative imaging biomarkers are replacing subjective visual assessment, improving reproducibility and enabling detection of subtle disease processes before they become clinically apparent

AI as Clinical Partner
Artificial intelligence is transforming from research curiosity to clinical necessity, enhancing workflow efficiency and diagnostic accuracy across all cardiovascular imaging modalities

Patient-Centered Imaging
The future of cardiovascular imaging is multimodality integration focused on answering specific clinical questions with the right test for the right patient at the right time

1. Compared to conventional CT, photon counting CT has
    a. Less Radiation Dose
    b. More Radiation Dose
    c. Same Radiation Dose
    d. No Radiation

2. Which of the following procedures does NOT typically use real time TEE imaging for guidance?
    a. Mitral clip
    b. LAA occlusion
    c. Transfemoral aortic valve replacement
    d. Mitral paravalvular leak closure

3. What is a major benefit of flurpiridaz over other PET radiotracers?
    a. Longer half life
    b. Shorter half life
    c. Low first-pass extraction
    d. Lower radiation dose