Scanner Spectral

Double Energie et Comptage Photonique

Principes et Premiers Résultats

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Plan

1. Rappel Techniques: Attenuation des RX
2. Double Energie:
   1. Principes
   2. Applications CV
3. Perspectives: SPCCT Scanner à Comptage Photonique:
Computed Tomography

• CT: Imaging technology widely used in the world

• CT: Major improvements the last 10 years
  – Large detectors:
    • Improved workflow with faster acquisitions
    • Improved diagnosis (PE, Stroke, Emergency Polytrauma etc..)
    • Cardio-vascular and coronary applications but still some limitations
    • Reduced dose of contrast agent
  – Iterative reconstructions
    • Reduced dose with improved S/N
X-Ray: Photons of High Energy
X-Ray Tube Spectrum
Probability of the photoelectric interaction is proportional to the atomic number $Z$ ($P \propto Z^3$).

Probability of a Compton interaction is almost independent of atomic number $Z$ and is directly proportional to the number of electrons per gram (electron density) of the material.
X-Ray Attenuation

- X-ray attenuation depends on the incident X-ray energy and on the effective atomic number of the traversed tissue

- Different tissues exhibit different combinations of photoelectric absorption and Compton scattering

\[
\mu(E) = \mu_p(E) + \mu_c(E) = \alpha_p f_p(E) + \alpha_c f_c(E)
\]

- Single X-ray acquisition cannot always help in the tissue characterization (finding out the contribution of each effect: photoelectric and Compton) and may lead to similar HU for different tissues
Double énergie

- Objectif : apporter une information spectrale supplémentaire

- Séparation hautes et basses énergies :
Double énergie

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- Objectif : apporter une information spectrale supplémentaire
- Séparation hautes et basses énergies :
Technology Paths to Dual-Energy Acquisition

**Dual Source**
Spectral mode: needs to be pre-selected
2 tubes (80 or 100/140 kVp)
Image Space

**kV Switch**
Spectral mode: needs to be pre-selected
Fast kV switching: 80/140kVp
Projection Space
(interpolations)

**Dual Spin**
Spectral mode: needs to be pre-selected
1st spin @ 80kVp
2nd spin @ 140kVp
Image Space

**Detection Based**
No spectral mode: SPECTRAL ALWAYS @ 120 kVp & 140 kVp
Tube mA modulation
Dose Neutral
Projection Space
Double énergie

- Objectif : apporter une information spectrale supplémentaire

- Séparation hautes et basses énergies :
  - Emission du tube polychromatique
  - Séparation des matériaux : iode, calcium…
    - Algorithmes de prédiction probabiliste (likelihood)
    - Cartographie : VNC, Energies (40->200 kV), iode, calcium
  - Correction du beam hardening
Photoelectric - Compton Decomposition

Material pairs

Material Specific Images

CT Image

Calcium Image

Iodine Image

Calcium-Iodine pair
Photoelectric - Compton Decomposition

Material pairs

Material Specific Images

CT Image  Iodine image  Water image

Water-Iodine pair
Photoelectric - Compton Decomposition

Virtual Mono Energetic Imaging

\[ \mu(E) = \mu_p(E) + \mu_c(E) = \alpha_p f_p(E) + \alpha_c f_c(E) \]
Virtual Monochromatic Spectral Imaging with Fast Kilovoltage Switching: Improved Image Quality as Compared with That Obtained with Conventional 120-kVp *

*a. 62-keV
b. 67-keV
c. 72-keV VMS imaging
d. conventional 120-kVp CT

*Radiology 2012 Matzumoto et al
Photoelectric - Compton Decomposition

Virtual Mono Energetic Imaging

40 keV

200 keV
Photoelectric - Compton Decomposition
Virtual Mono Energetic Imaging

Iodine Boost @ low keV

Conventional 120 kV CT Image

55 keV Mono-Energy CT Image
Photoelectric - Compton Decomposition

*Virtual Mono Energetic Imaging*

Artefact reduction @ high keV
Impact of monochromatic coronary computed tomography angiography from single-source dual-energy CT on coronary stenosis quantification
Impact of monochromatic coronary computed tomography angiography from single-source dual-energy CT on coronary stenosis quantification

J Stehli et al. / Journal of Cardiovascular Computed Tomography 10 (2016)
Impact of monochromatic coronary computed tomography angiography from single-source dual-energy CT on coronary stenosis quantification

J. Stehli et al. / Journal of Cardiovascular Computed Tomography 10 (2016)
Diagnostic Accuracy of Rapid Kilovolt Peak–Switching Dual-Energy CT Coronary Angiography in Patients With a High Calcium Score

JACC: CARDIOVASCULAR IMAGING, 2015
Perfusion

- Réalisation d'une double acquisition* :
  - Repos (coronaires)
  - Stress pharmacologique ou effort (basse dose)

- Reconstruction itérative : dose et amélioration du contraste/détexion iode

Perfusion
Analyse cardiaque
Evaluation d’un défect de perfusion.
—50-year-old man with recurrent chest pain after prior myocardial infarction in left anterior descending artery territory and surgical revascularization. A, Short-axis images of SPECT (A) and MRI (B) examinations at rest show subendocardial perfusion defect (arrows).
50-year-old man with recurrent chest pain after prior myocardial infarction in left anterior descending artery territory and surgical revascularization. Corresponding short-axis cross-section of contrast-enhanced dual-energy CT study at rest, reconstructed as merged gray-scale image with superimposed iodine distribution color map.

Vliegenthart R et al. AJR 2012;199:S54-S63
Perfusion – Double énergie

- Amélioration de la quantification
- Correction du beam hardening (paroi postérieure +++)

* AJR 2010; 195:639-646
Dual-energy CT might be a better way for optimising myocardial and coronary artery imaging.

Pan et al, International Journal of Cardiology March 2016
Spectral Photon Counting CT
SPCCT
Imaging all the Photons......

Common Scintillating Detector

Photon counting detector

Figure 6.14 Schematic diagram of a semiconductor direct-conversion detector.
Dual Energy CT
Dual Layer Detector (PHILIPS)

Photon counting CT
Direct Conversion Detector

X-Ray Tube Spectrum

Detector

Low density/High Light Output Scintillator
High Output Scintillator

Integrating ASIC

Direct Conversion Detector

Counting ASIC
Schematic diagram of energy discrimination

1. Absorbed single X-ray photon
2. Charge Pulse
3. Pulse height proportional to x-ray photon energy
4. Discriminating
5. Photon Counting thresholds

Stored counts of all energy windows, for each reading time period

Counts vs. Photon energy
Potential Benefits

- High Spatial Resolution
- K-edge Imaging
- Multiple material characterization
- Precise energy separation
- Low-contrast resolution
- Low Dose
Methods and Materials

Biological material:
- 8 calcified atherosclerotic plaques
- 10 lipid-rich atherosclerotic plaques
- Filled and immersed into an Iodine solution

Photon Counting Multi-Energy CT:
- 70 keV, 20 mAs/Slice
- FOV: 60 mm
- Resolution: 0.1x0.1x0.2 mm³
- Scan time: 200 sec/slice

Photon counting CT, Philips, Germany
Significant differences between all elements for **Photoelectric absorption** and **Iodine concentration** (p<0.008)
No difference for **Compton scattering** between vessel wall, perivascular fat and lipid-rich plaques
Results

Iodine map and calcifications

CT-like image

Iodine map
Molecular imaging

Figure 3: Images of artery phantom. (a) Labeled CT image; (b) spectral CT images; and (c) overlay of gold, iodine, photoelectric, and Compton images are shown. $Ca_3(PO_4)_2$ = calcium phosphate.
Molecular imaging

• Gold high-density lipoprotein nanoparticle contrast agent (Au-HDL)*
  For characterization of macrophage burden, calcification and stenosis of atherosclerotic plaques
  In Apolipoprotein E knockout mice

*Comode et al, Radiology 2013
Molecular imaging

- Fibrin using bismuth loaded nanoparticles

D Pan et al Computed Tomography in Color: NanoK-Enhanced Spectral CT
Installation of 1st iCT-based preclinical SPCCT – prototype @ CERMEP Lyon

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Platform</td>
<td>Philips iCT</td>
</tr>
<tr>
<td>Tube voltages [kVp]</td>
<td>80, 100, 120</td>
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<tr>
<td>Tube currents [mA]</td>
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<td>Focal spot [mm x mm]</td>
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<td>Gantry rotation [s]</td>
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<td>Spatial Resolution [lp/cm]</td>
<td>&gt; 20</td>
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<tr>
<td>FOV [mm]</td>
<td>168</td>
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<tr>
<td># energy bins</td>
<td>&gt; 2</td>
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<tr>
<td>Sensor Material</td>
<td>CZT</td>
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<tr>
<td>Sensor Thickness</td>
<td>2 mm</td>
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</tbody>
</table>
Spatial Resolution

Line-Pairs plastic phantom

Scan of anatomical leg phantom
Spatial Resolution *Stenosis Phantom*

- **Scan Parameter:**
  - Scan Type: Axial (stack)
  - 120kVp 50mA
  - Rotation 1sec

- **Reconstruction:**
  - HU Image
  - Filter: Standard
  - Voxel Size: 0.2 x 0.2 x 0.25 [mm]

Mean: 1850
Spatial Resolution $Stent$

Standard CT

SPCCT
X-RAY

X-Ray Rabbit
Acquisition In-Vivo SPCCT : Contrast

• Acquisition : Axial, Z coverage = 2 mm, 120 kVp, 100 mA
• Reconstruction : FOV 80, Matrix size 1024, pixel size= 0,08, slice thickness 0,1 mm, Detail filter
Acquisition In-Vivo SPCCT : Contrast

- **Figure 3**: Volume rendering of 2mm coverage with media contrast agent
Material Decomposition  *Contrast Specificity Images*

Axial : 120kVp 100mA  

HU  
WL: 1000  WW: 0  SW: 2mm  :  Standard  

Water [mg/cc]  
WL: 790  WW: 2764  SW: 2mm  :  Standard  

Gadolinium [mg/cc]  
WL: 3.64  WW: 4.38  SW: 2mm  :  Smooth  

Iodine [mg/cc]  
WL: 18.28  WW: 35.26  SW: 2mm  :  Standard  

Gold [mg/cc]  
WL: 4.76  WW: 6.02  SW: 2mm  :  Smooth  

Partnership with: University of Pennsylvania
Rabbit Gold Contrast

11.2cc Gold (peg 65mg/cc) injected 120 kVp 100 mA
Rabbit Gadolinium Contrast

50 seconds after Gadolinium Injection.

- Cavity: 2.92 [mg/cc]
- Parenchyma: 1.63 [mg/cc]
CARDIAC ANGIOGRAPHY

Parameters:
- Thickness 2 mm
- No Filter
- L1172; W311

Fig 1: Cardiac angiography after dynamic injection of Gold (12 mL at 1 cc/s) (gif) : 30 seconds of acquisition starting 5 s after injection, 15 cycles of 2 seconds

Parameters:
- Thickness 2 mm
- Gaussian filter 2 mm

Fig 3: Reconstruction of the Kedge of Gold. Cardiac angiography after dynamic injection of Gold (12 mL at 1 cc/s) (gif) : 30 seconds of acquisition, 15 cycles of 2 seconds

Fig 2: Cardiac angiography after dynamic injection of Iodine (3 mL at 1 cc/s) and past injection of gold (gif) : 30 seconds of acquisition, 15 cycles of 2 seconds

Fig 4: Reconstruction of the Kedge of Gold. Cardiac angiography after dynamic injection of Iodine (3 mL at 1 cc/s) and past injection of gold (gif) : 30 seconds of acquisition, 15 cycles of 2 seconds
Fig 1: Dynamic angiography during 30 s with reconstruction of Kedge of Gold after injection of iodine (3 mL at 1 cc/s) and past injection of gold (12 mL) (gif)

Fig 2: Dynamic angiography during 30 s with reconstruction of material decomposition of Iodine after injection of iodine (3 mL at 1 cc/s) and past injection of gold (12 mL) (gif)
Material Decomposition *Contrast Specificity Images*

Applications of Dual Contrast Agents

Graph showing Hounsfield Units (HU) for iodine (I) and gadolinium (Gd) with corresponding grayscale images of a phantom and a polyp.

**Phantom**
- Unenhanced polyp
- Iodine

**Polyp**
- Gadolinium enhanced polyp

Technical specifications:
- Axial: 120kVp 50mA
- HU: WL -350 WW 1400
- Gd: WL545 WW45
- I: WL690 WW255

Partnership with: Technical University Munich
**Rabbit Gold & Iodine Contrast**

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<th>Conventionnal</th>
<th>Gold</th>
<th>Iodine</th>
<th>Overlay</th>
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<td><strong>T1</strong></td>
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<td>![Gold Image]</td>
<td>![Iodine Image]</td>
<td>![Overlay Image]</td>
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<tr>
<td><strong>T2</strong></td>
<td></td>
<td>![Gold Image]</td>
<td>![Iodine Image]</td>
<td>![Overlay Image]</td>
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<tr>
<td><strong>T3</strong></td>
<td></td>
<td>![Gold Image]</td>
<td>![Iodine Image]</td>
<td>![Overlay Image]</td>
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3 cc Iodine (400 mg/cc) injected 120 kVp 100 mA
Rabbit Gold & Iodine Contrast

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<tr>
<td>T3</td>
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<td><img src="image9.png" alt="Image" /></td>
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H2020 SPCCT: Lyon university coordinator

To develop and validate a widely accessible, new quantitative and analytical imaging technology combining:

- Spectral Photon Counting Computed Tomography (SPCCT) AND
- Dedicated Contrast Agents

To accurately detect, characterize and monitor neurovascular and cardiovascular disease:

- Ultra-low dose imaging
- CA dose reduction (reduction of entire scans)
- Quantitative imaging (follow-up)
- Functional imaging (K-edge)
- Higher spatial resolution

Ex-vivo, pre-clinical (hours, 100 µA)

In-vivo pre-clinical (seconds, 100 mA)

Clinical (sub-seconds, 1000 mA)
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