Usefulness of New CT Technologies for Interventional Cardiovascular Procedures

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1. Fusion imaging for structural heart interventions

2. Dual energy / Spectral CT for CV imaging

3. Early access with a compact cardiac-oriented CT
1. Fusion Imaging in Multimodality Medical Imaging - Principles

• Why? To combine the relative diagnostic advantages of two different modalities into a single screen shot (static or real time)

• How? by creating a grid for each image acquired in each modality and then linking each pixel in the two modalities via a “similarity function”
Fusion Imaging – Principles cont.

• Alternatively, linking “hinge points” or common “easy to find” markers which can be linked in both studies
  – For example hepatic veins in liver imaging (U/S + MRI)
Principles of Image Co-Registration

• **Rigid registration**: combining two acquisitions and 2 similar anatomic grids
  - for example: 2 repeated head CT’s

• **Elastic registration**: changing / bending the grid points of one image to fit the grid of the other modality (to allow easier anatomic 3D visualization, not necessarily for quantitative analysis)
“Real Time” Co-Registration
(2 simultaneous cine loops)

• Clinical need is unclear

• Requires extremely fast computer algorithms

• Most cardiac CT co-registration algorithms do not require multi-phasic acquisition (i.e. retrospective gating)
Image Fusion for CV Procedures
Electrophysiology - EP Lab Integration

3D Image Data

Automatic Heart Segmentation

Left Atrium & PV Assessment

EP Planning
Structural Heart Interventions
TAVI - Transcatheter Aortic Valve Implantation

• TAVI is non-inferior (Partner 5 years study) or superior (CoreValve 2 year study) to surgical AVR in high risk AS patients

• TAVI is usually performed under fluoroscopic and sometimes with echocardiographic guidance

• Structural heart disease intervention (TAVI, LAA occlusion, transcatheter mitral valve repair) are estimated to grow at an annual rate of 30%

![Graph showing expected TAVR procedures in USA from 2013 to 2018.](source: MRG - US Markets for Heart Valve Devices 2014)
CT TAVI Planning – PC Based Portal Application

- Automated generation of most commonly needed planes required for TAVI planning
  - the coronary ostia
  - automated planes detection and dimensions measurements of
    - the aortic annulus
    - left ventricular outflow tract (LVOT)
    - sinotubular junction
    - sinus of valsalva
    - ascending aorta
  - and distance to coronary ostia for TAVI-device sizing
TAVI planning  (IntelliSpace portal)

Emerging Application

CT-TAVI
Preparing the CT Image for TAVI

Heart-Navigator (may be useful for both native and VIV TAVI)

**Step 1. Automatic segmentation.** A DICOM CT dataset is automatically segmented to show anatomical structures and landmarks.

**Step 2. Automatic Measurements**
With one click, automatic measurements relevant for TAVI procedures are provided: the diameters of the left ventricular outflow tract, aortic valve annulus, sinus of valsalva, sinotubular junction and ascending aorta, together with the distances of the ostia of the LCA and RCA to the valve plane.

**Step 3. Device selection and view planning.**
Commonly used projection angles (based on the calculated planes and landmarks) are automatically provided and can be recalled to select the most preferred X-ray viewing angle for use during the procedure. Additionally, personal projection angles can be stored. Different virtual device templates for the most commonly used TAVR/TAVI devices can be used to check the size of the device.

**Step 4. Import and match CT volume to X-ray.**
The software automatically imports the live X-ray images. The user manually matches the 2D X-ray images with the 3D dataset.

**Step 5. Live overlay image.**
During the procedure, you can use the 3D live overlay on the live X-ray image to get real-time feedback as you navigate through the vasculature. The overlay automatically follows the C-arm position and table and C-arm movements are compensated to keep the 3D image matched with the live fluoroscopy image.
CT- Cath Lab Integration

CT- TAVI Planning

Aorta Extraction & Analysis

3D Image Data
Typical Use of Fusion Imaging for TAVI

Fig. 4. HeartNavigator overlay during balloon deployment. Red outline marks the aortic root derived from the CTA.

Fig. 5. HeartNavigator overlay during final positioning of the valve.

Fig. 6. Angiography after initial valve deployment. Arrow 1 indicates sufficient distance between offspring of the LCA and the valve device. Arrow 2 paravalvular leak.

Fig. 7. Angiography after balloon post-dilatation, showing no residual paravalvular leak.
2. Material Specific Imaging  
(Dual Energy / Spectral CT)

• Use each tube at a different kV to exploit the kV-dependent nature of CT #

• Off-line post-processing for material / disease selective images
Dual Energy: What is it?

Significant difference in the linear attenuation coefficient at two different energies

![Graph showing Dual Energy comparison]

- **Iodine**
  - 56 kV: Large increase
  - 76 kV: Small increase

- **Bone**
  - 56 kV: Small increase
  - 76 kV: Large increase

**Energy / keV**

- 10
- 30
- 50
- 70
- 90
- 110
- 130
- 150

**Attenuation**

- 10E+00
- 10E+01
- 10E+02
Material Decomposition

Characterization of different tissue types

- Fat
- Tissue
- Iodine

CT value @ 80 kV
CT value @ 140 kV
Figure Legend:
Schematic Illustration of 4 Different Approaches for Obtaining Dual-Energy Information
(A) Dual source-detector pairs with each source operating at a different tube voltage. Each x-ray source covers a different scan field. (B) Single source-detector pair with the source capable of rapid voltage switching in a single gantry rotation. (C) Single source-detector pair with a dual-layer detector made of 2 different materials capable of differentiating between low-energy (upper layer) and high-energy (bottom layer) photons, with the source operating at constant tube voltage. (D) Single source-detector pair with tube voltage switching between sequential gantry rotations.
The IQon Detector

- 16×16×2 tile with the same pitch as iCT
- Top layer scintillator optimized for absorbing low energy photons
- No spectral filtering in detection pass i.e. no photons lost
- Light collected from the side of the scintillator to improve the coupling of light to the photo-diode
- Tungsten backbone protects the photo diode from X-ray, minimizes cross talk between detectors and provides mechanical robustness
- 2mm thick (in iCT 1.4mm) bottom layer (GOS) scintillator for absorbing >99% of the incident photons

The Low E scintillator (low density Garnet):
- Spectral properties
- High light output
- Low Afterglow
- Good temperature stability
NanoPanel Prism
Perfect alignment
Simultaneous alignment in time and space

X-Rays

Top Scintillator

Bottom Scintillator: 2-mm GOS+

Side-looking photodiode array

Low Energy Raw data

High Energy Raw data

Combined Raw data

E1 image

E2 image

CT image

Top scintillator
Effective atomic number small but does not sacrifice light output
Thickness optimized for energy separation and low-energy image noise

Bottom scintillator absorbs 99.5% of high-energy spectrum
Energy Map with uric acid and bone slopes
Spectral CT: Gout
IQon Spectral CT:
Step & Shoot Cardiac reconstructed at different energy levels

50keV

70keV

90keV

150keV

Courtesy: University Hospitals Case Western Reserve, Cleveland, OH
IQon Cardiac CT
Contrast enhancement with mono-energy images

MonoE 50keV
MonoE 70keV
MonoE 90keV
MonoE 140keV

Courtesy: University Hospitals Case Western Reserve, Cleveland, OH
Improved contrast enhancement
20 cc’s of IV contrast

Conventional 120kVp

40 keV

Courtesy: Dr. H Bezerra, Dr. RC Gilkeson, University Hospitals, Cleveland, OH
Coronary Stenosis Assessment
Reduced Calcium Blooming

Courtesy: University Hospitals Case Western Reserve, Cleveland, OH
Spectral / Dual-Energy CT for the Evaluation of Coronary Atherosclerosis
Cardiac Oriented CT Scanner

Background

- Cardiac CT Angiography became a valid option since the introduction of multi row 16, 40 and 64 slice CT scanners.
- To date, all procedures are done on whole body scanners designed and built for general purpose imaging.
- A new type of “Stereo CT” dual tube scanner optimized for cardiovascular imaging is under evaluation.
CCTA has to show good image quality
Because other modalities have better spatial resolution...

CT Angiography
Resolution: 230-600µm

Angiography
200µm

IVUS
100µm

OCT
10µm
Stereo CT Technology

• Two overlapping cone beams facing a single detector array rotate about the patient
• Coverage sufficient for whole heart scanning in a single beat
Animal Model Results

LAD
Cardiac Oriented CT in the CCU
Lady Davis Carmel Medical Center – Haifa, Israel
First Human Case of CCTA – Arineta

December 2015
Spectral CT – A story from the holy land
Is this rock the first man-made art?

NYTIMES: Anthropologists discovered a 55,000-year-old skull fossil in the Manot Cave in western Galilee in 2008, and it was subjected to years of analysis.
~40,000 years old stone from Manot cave, Israel with human made engravings. A CT scan enabled us to reveal the difference between natural cracks (A) and human intended engraving (3B) in the stone. The interruption in the continuity of the crust (C) opposed to natural cracks (D) emphasis the intended human actions.

**Spectral CT in the service of Archeology**

Courtesy of Tel Aviv University
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Summary

• Rigid or Elastic co-registration allow image fusion from two different data-sets or two different modalities

• Fusion imaging may be helpful to plan or guide CV interventions in patients with structural heart diseases

• Use of multiple tube outputs or dedicated detectors allow better assessment of the cardiac tissue

• Material specific assessment with spectral CT may improve diagnostic accuracy and possibly overcome common CT artifacts for vascular / coronary CTA and myocardial perfusion imaging

• Cardiac dedicated “stereo-CT” may increase the use of CT technology by interventional cardiologists
Thank you