PHILIPS

Spectral CT for Radiation Oncology

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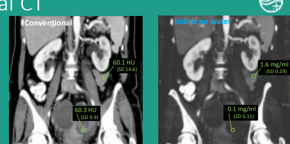
Sr. Clinical Scientist CT and Radiation Oncology
15-07-2019

innovation + you

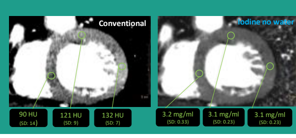
Limitations of conventional CT

HU is not quantitative

Two tissues with **different composition** or different iodine uptake can show **the same average different attenuation**.



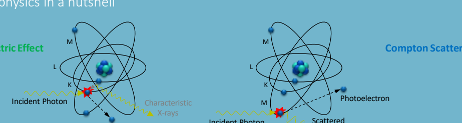
Artifacts can compromise diagnosis and quantification.



Slide Courtesy: Gregor Pahn

Dual-energy CT

X-ray physics in a nutshell



Measured Attenuation = Photoelectric Effect + Compton Scatter

$$\mu = \mu_P + \mu_C$$

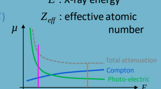
$$\mu = a_P(Z_{eff}) \cdot f_P(E) + a_C(Z_{eff}) \cdot f_C(E)$$

E : X-ray energy

Z_{eff} : effective atomic number

Energy-dependent part well known: $f_P(E),\ f_C(E)$

Material-dependent part unknown: $a_P(Z_{eff}), a_C(Z_{eff})$

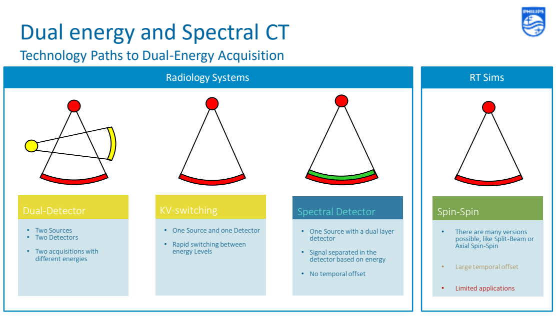


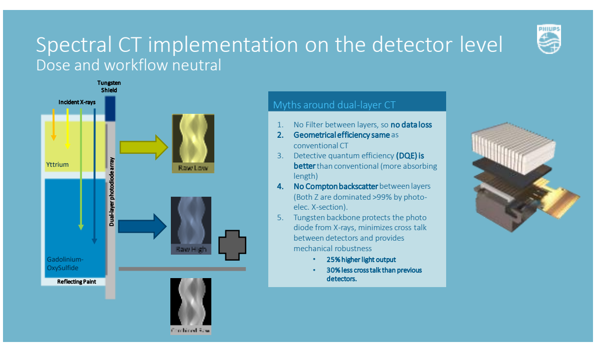
We need 2 equations to solve for 2 unknowns:

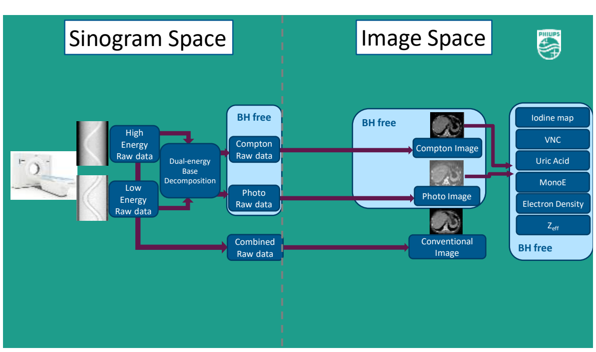
$$\mu(E_1) = a_P\ f_P(E_1) + a_C\ f_C(E_1)$$

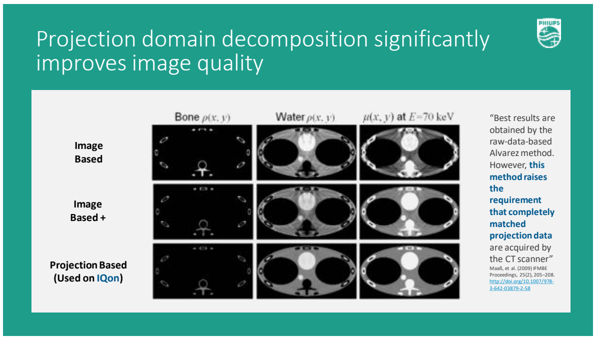
$$\mu(E_2) = a_P\ f_P(E_2) + a_C\ f_C(E_2)$$

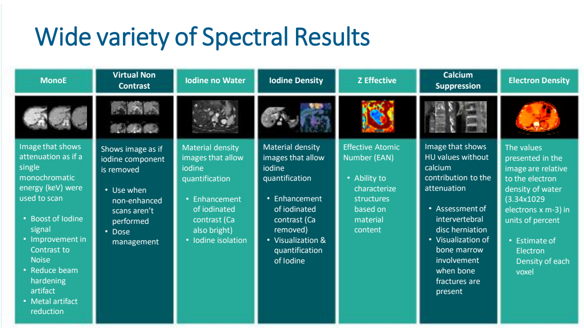
Slide Courtesy: Gregor Pahn

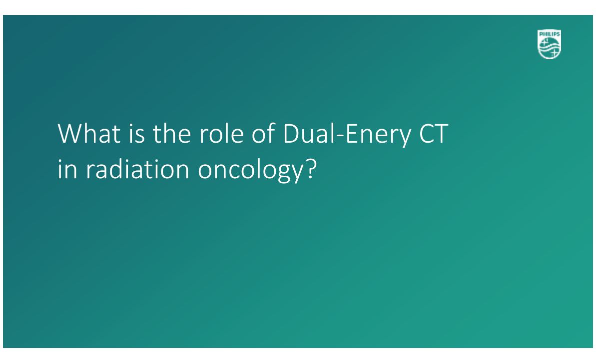

Dual energy and Spectral CT
Technology Paths to Dual-Energy Acquisition
Radiology Systems
RT Sims
Dual-Detector
Two Sources
Two Detectors
Two acquisitions with different energies
KV-switching
One Source and one Detector
Rapid switching between energy Levels
Spectral Detector
One Source with a dual layer detector
Signal separated in the detector based on energy
No temporal offset
Spin-Spin
There are many versions possible, like Split-Beam or Axial Spin-Spin
Large temporal offset
Limited applications


Spectral CT implementation on the detector level
Dose and workflow neutral
Tungsten Shield
Incident X-rays
Yttrium
Gadolinium-OxySulfide
Reflecting Paint
Dual-layer photodiode array
Raw Low
Raw High
Myths around dual-layer CT
1. No Filter between layers, so no data loss
2. Geometrical efficiency same as conventional CT
3. Detective quantum efficiency (DQE) is better than conventional (more absorbing length)
4. No Compton backscatter between layers (Both Z are dominated >99% by photo-elec. X-section).
5. Tungsten backbone protects the photo diode from X-rays, minimizes cross talk between detectors and provides mechanical robustness
25% higher light output
30% less cross talk than previous detectors.


Sinogram Space
Image Space
High Energy Raw data
Low Energy Raw data
Dual-energy Base Decomposition
BH free
Compton Raw data
Photo Raw data
Combined Raw data
BH free
Compton Image
Photo Image
Conventional Image
Iodine map
VNC
Uric Acid
MonoE
Electron Density
Z_{eff}
BH free


Projection domain decomposition significantly improves image quality
Bone ρ(x, y)
Water ρ(x, y)
μ(x, y) at E=70 keV
Image Based
Image Based +
Projection Based (Used on IQon)
"Best results are obtained by the raw-data-based Alvarez method. However, this method raises the requirement that completely matched projection data are acquired by the CT scanner"
Maaß, et al. (2009) IFMBE Proceedings, 25(2), 205–208.
http://doi.org/10.1007/978-3-642-03879-2-58


Wide variety of Spectral Results
MonoE
Image that shows attenuation as if a single monochromatic energy (keV) were used to scan
• Boost of Iodine signal
• Improvement in Contrast to Noise
• Reduce beam hardening artifact
• Metal artifact reduction
Virtual Non Contrast
Shows image as if iodine component is removed
• Use when non-enhanced scans aren't performed
• Dose management
Iodine no Water
Material density images that allow iodine quantification
• Enhancement of iodinated contrast (Ca also bright)
• Iodine isolation
Iodine Density
Material density images that allow iodine quantification
• Enhancement of iodinated contrast (Ca removed)
• Visualization & quantification of Iodine
Z Effective
Effective Atomic Number (EAN)
• Ability to characterize structures based on material content
Calcium Suppression
Image that shows HU values without calcium contribution to the attenuation
• Assessment of intervertebral disc herniation
• Visualization of bone marrow involvement when bone fractures are present
Electron Density
The values presented in the image are relative to the electron density of water (3.34x1029 electrons x m-3) in units of percent
• Estimate of Electron Density of each voxel

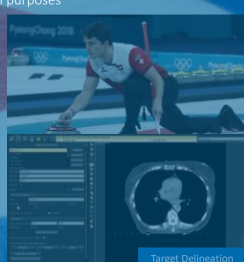

What is the role of Dual-Enery CT in radiation oncology?

Radiotherapy as a game of curling

Radiotherapy as a game of curling

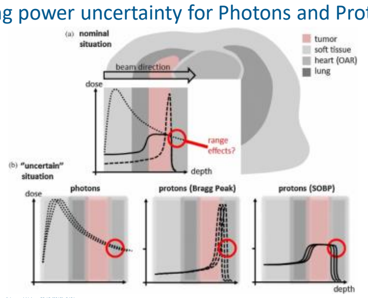
Treatment planning imaging serves two main purposes

Stopping power / Dose Calculation



Target Delineation

Stopping power uncertainty for Photons and Protons



Knopf, Antje-Christin, and Antony Lomax. Physics in medicine and biology 58.15 (2013): R131.

Proton stopping power from ED and Z-effective

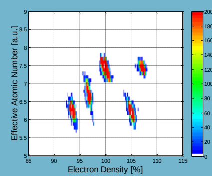
Medical Physics
The International Journal of Medical Physics Research and Practice

Research Article

Accuracy of electron density, effective atomic number, and iodine concentration determination with a dual-layer dual-energy computed tomography system

Chia-ho Hua, Nadav Shapira, Thomas E. Merchant, Paul Klahr, Yoad Yagil

First published: 6 April 2018 | https://doi.org/10.1002/mp.12903



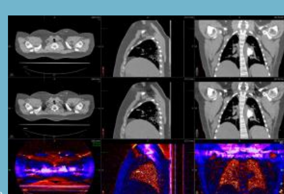
"The accuracy of ED and Z_{eff} measurement at 120 kVp was no worse than that at 140 kVp."

Quantitative Electron Density map

ED images directly calculated from IQon

HU images (IQon iDose4 level 3)

Difference



Courtesy of Dr. Hua, Dep. Radiation Oncology, St. Jude Children's Research Hospital

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Mei, K., Ehn, S., Oechsner, M., Kopp, F. K., Pfeiffer, D., Fingerle, A. A., … Noël, P. B. (2018). Dual-layer spectral computed tomography : measuring relative electron density. https://doi.org/10.1186/s41747-018-0051-8

Hua, C., Shapira, N., Merchant, T. E., Klahr, P., & Yagil, Y. (2018). Accuracy of electron density, effective atomic number, and iodine concentration determination with a dual-layer dual-energy computed tomography system. *Medical Physics*. http://doi.org/10.1002/mp.12903

Stopping power map for Proton Therapy

- Yang *et al.*, PMB (2010):
  RMSE: SECT: **0.9%**, DECT: **0.3%**
- Hünemohr *et al.*, Z. Med. Phys. (2013):
  Mean abs: SECT: **1.5%±1.6%**, DECT: **0.5%±0.4%**
- Hansen *et al.*, Acta Oncol. (2015):
  RMSE: SECT: **2.7%**, DECT: **0.5%**, proton CT: **0.2%**
- Zhu and Penfold, Med. Phys. (2016):
  RMSE: SECT: **2.3%**, DECT: **1.5%**

Dosimetric comparison of stopping power calibration with dual-energy CT and single-energy CT in proton therapy treatment planning

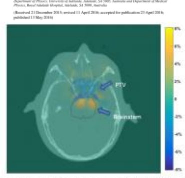
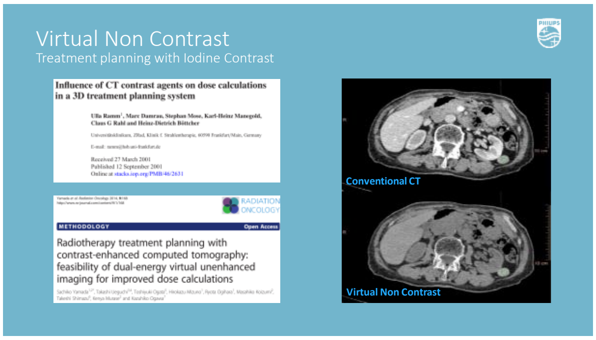
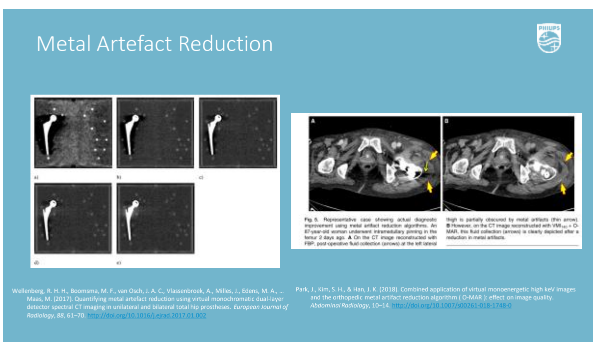


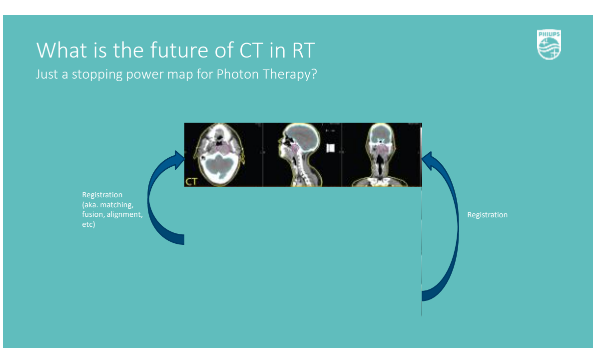
FIG. 8. Relative dose difference between doses calculated with the SECT and DECT image sets. Relative differences calculated as dose resulting from SECT, subtracted from that resulting from DECT, and normalized by a global prescription value of 2 Gy.

Zhu, J., & Penfold, S. N. (2016). Dosimetric comparison of stopping power calibration with dual energy CT and single energy CT in proton therapy treatment planning. *Medical Physics*, *43*(6), 2845–2854.

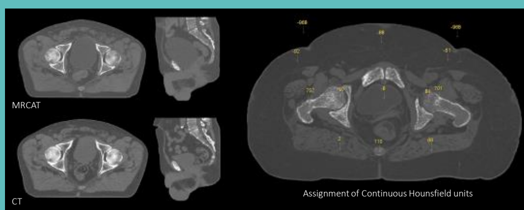
Slide Courtesy: Vicki Trier Taasti, Aarhus University Hospital


Virtual Non Contrast
Treatment planning with Iodine Contrast
Influence of CT contrast agents on dose calculations in a 3D treatment planning system
Ulla Ramm[1], Marc Damrau, Stephan Mose, Karl-Heinz Manegold, Claus G Rahl and Heinz-Dietrich Böttcher
Received 27 March 2001
Published 12 September 2001
Online at stacks.iop.org/PMB/46/2631
RADIATION ONCOLOGY
METHODOLOGY
Open Access
Radiotherapy treatment planning with contrast-enhanced computed tomography: feasibility of dual-energy virtual unenhanced imaging for improved dose calculations
Conventional CT
Virtual Non Contrast


Metal Artefact Reduction
Wellenberg, R. H. H., Boomsma, M. F., van Osch, J. A. C., Vlassenbroek, A., Milles, J., Edens, M. A., … Maas, M. (2017). Quantifying metal artefact reduction using virtual monochromatic dual-layer detector spectral CT imaging in unilateral and bilateral total hip prostheses. European Journal of Radiology, 88, 61–70. http://doi.org/10.1016/j.ejrad.2017.01.002
Park, J., Kim, S. H., & Han, J. K. (2018). Combined application of virtual monoenergetic high keV images and the orthopedic metal artifact reduction algorithm (O-MAR): effect on image quality. Abdominal Radiology, 10–14. http://doi.org/10.1007/s00261-018-1748-0

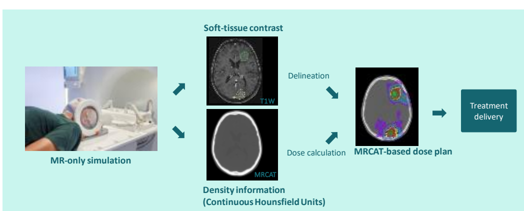

What is the future of CT in RT
Just a stopping power map for Photon Therapy?
CT
Registration (aka. matching, fusion, alignment, etc)
Registration

CT-like density information at the MR console
Continuous Hounsfield Units



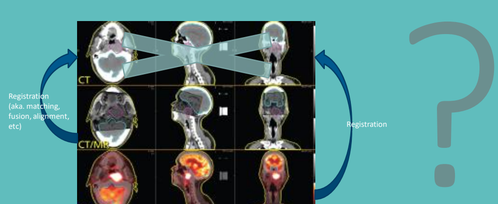
1 Ingenia MR-RT 1.5T. Images courtesy: Turku University Hospital, Finland

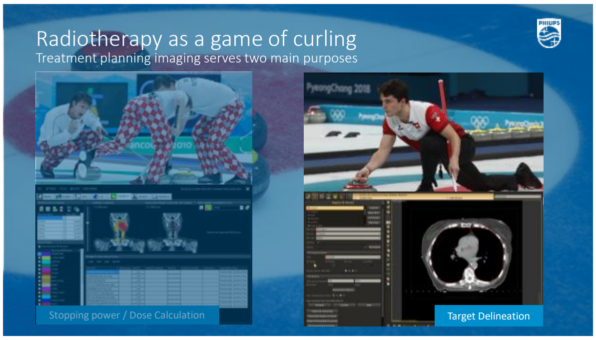
MR-only simulation brain[1]
Attenuation maps and anatomical information based on MR data only

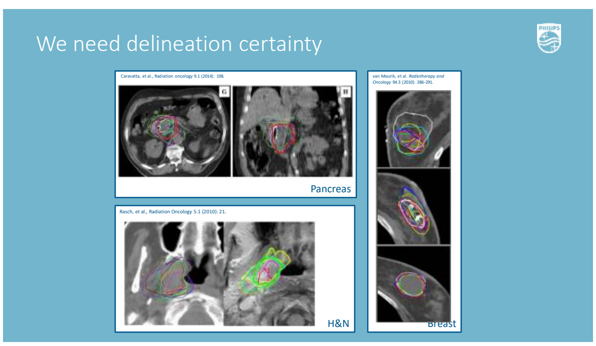


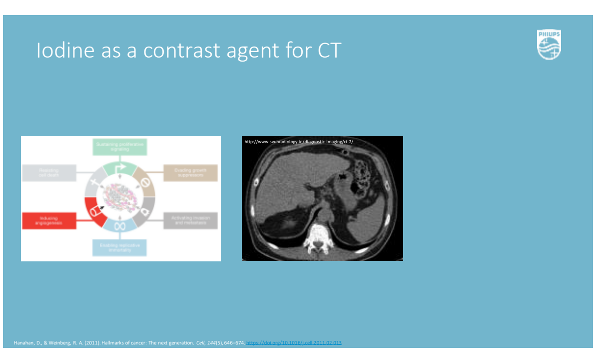
MRCAT (MR for Calculating ATtenuation). MRCAT brain is work in progress, not CE marked and not available for sale.
Ingenia MR-RT 1.5T. Images courtesy of Turku University Hospital, Finland

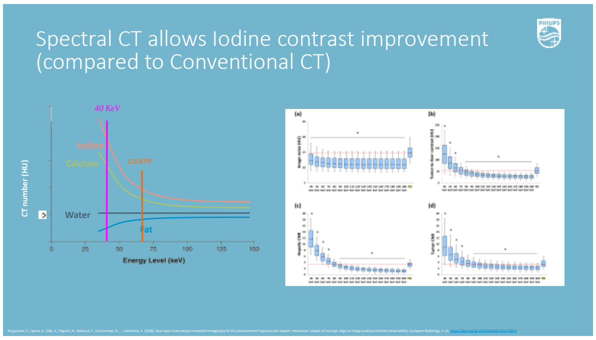
What is the future of CT in RT
Just a stopping power map?

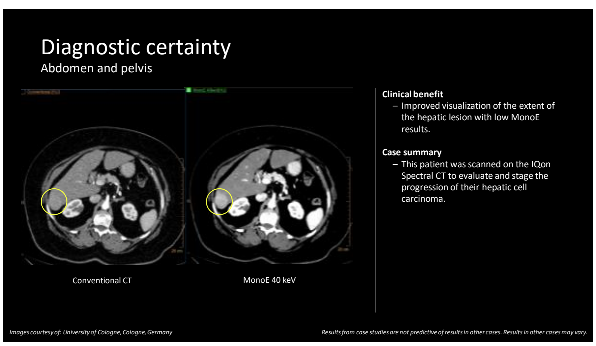


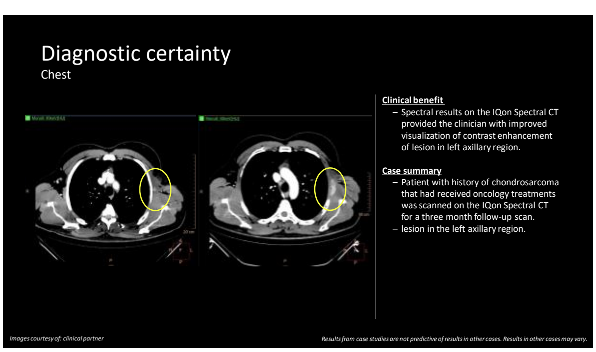

Radiotherapy as a game of curling
Treatment planning imaging serves two main purposes
Stopping power / Dose Calculation
Target Delineation


We need delineation certainty
Caravatta, et al., Radiation oncology 9.1 (2014): 198.
Pancreas
Rasch, et al., Radiation Oncology 5.1 (2010): 21.
H&N
van Mourik, et al. Radiotherapy and Oncology 94.3 (2010): 286-291.
Breast


Iodine as a contrast agent for CT
Hanahan, D., & Weinberg, R. A. (2011). Hallmarks of cancer: The next generation. Cell, 144(5), 646–674. https://doi.org/10.1016/j.cell.2011.02.013


Spectral CT allows Iodine contrast improvement
(compared to Conventional CT)
40 KeV
Iodine
Calcium
120 KVP
Water
Fat
CT number (HU)
0
0
25
50
75
100
125
150
Energy Level (keV)
(a)
(b)
(c)
(d)


Diagnostic certainty
Abdomen and pelvis
Conventional CT
MonoE 40 keV
Clinical benefit
– Improved visualization of the extent of the hepatic lesion with low MonoE results.
Case summary
– This patient was scanned on the IQon Spectral CT to evaluate and stage the progression of their hepatic cell carcinoma.
Images courtesy of: University of Cologne, Cologne, Germany
Results from case studies are not predictive of results in other cases. Results in other cases may vary.


Diagnostic certainty
Chest
Clinical benefit
– Spectral results on the IQon Spectral CT provided the clinician with improved visualization of contrast enhancement of lesion in left axillary region.
Case summary
– Patient with history of chondrosarcoma that had received oncology treatments was scanned on the IQon Spectral CT for a three month follow-up scan.
– lesion in the left axillary region.
Images courtesy of: clinical partner
Results from case studies are not predictive of results in other cases. Results in other cases may vary.

Spectral CT drastically improves Tumour contrast

European Radiology
https://doi.org/10.1007/s00330-018-5511-2

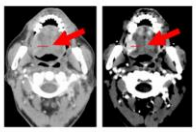
HEAD AND NECK

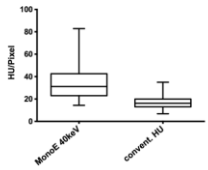
Improved detection rates and treatment planning of head and neck cancer using dual-layer spectral CT

Fabian K. Lohöfer[1] · Georgios A. Kaissis[1] · Frances L. Köster[1] · Sebastian Ziegelmayer[1] · Ingo Einspieler[1] · Carlos Gerngross[1] · Michael Rasper[1] · Peter B. Noel[1] · Steffen Koerdt[2,3] · Andreas Fichter[2] · Ernst J. Rummeny[1] · Rickmer F. Braren[1]

Received: 21 February 2018 / Revised: 17 April 2018 / Accepted: 20 April 2018

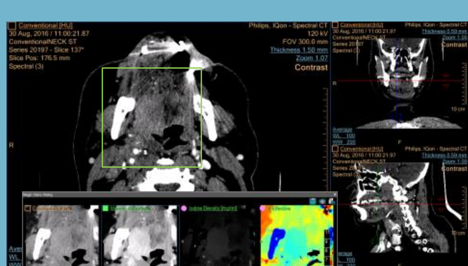
— MonoE 40keV
·· convent. HU





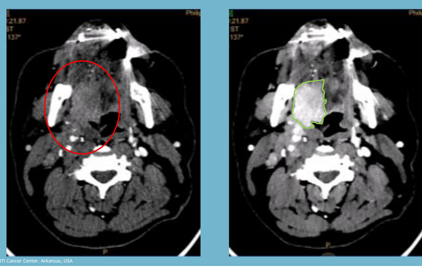
Spectral delineation in Radiotherapy

Head & Neck



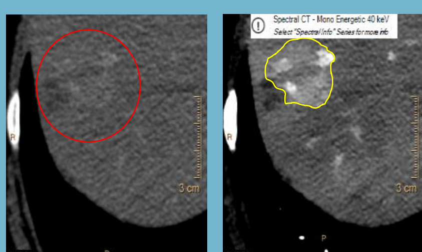
Images courtesy of CARTI Cancer Center, Arkansas, USA

Head & Neck



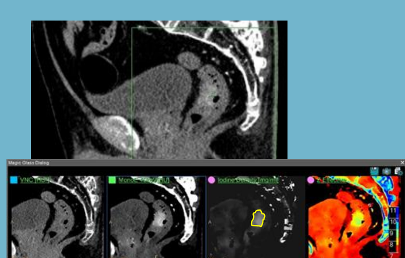
Images courtesy of CARTI Cancer Center. Arkansas, USA

Liver Metastasis



Images courtesy of Århus University Hospital, Denmark

Rectal Cancer



Images courtesy of Kumamoto Chuo Hospital, Japan

Prostate Cancer

Images courtesy of Aarhus University Hospital, Denmark

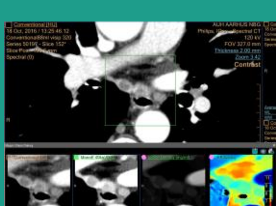
Staging

- FDG PET is now commonly used for target definition in RT planning for:
  - Breast cancer (24.8% of total RT treatments)
  - Lung cancer (19.7% of total RT treatments)
  - Head and Neck cancer (6.8% of total RT treatments)
  - Rectal cancer (6.2% of total RT treatments)
  - Esophageal cancer (2.1% of total RT treatments)

Borras, Josep M., et al. "How many new cancer patients in Europe will require radiotherapy by 2025? An ESTRO-HERO analysis." *Radiotherapy and Oncology* 119.1 (2016): 5-11.

Staging

Lung node involvement



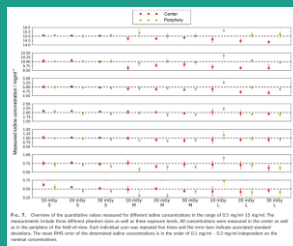
For rectal cancer:
"There were no difference in the accuracy in lymph node staging between DECT and MRI in this first attempt to apply DECT to the preoperative staging. But it might give additional information if combined with MRI."
Al-Najami, I., et al. "Dual-energy CT can detect malignant lymph nodes in rectal cancer." European Journal of Radiology (2017).

For laryngeal cancer:
"Extralaryngeal spread can be identified on CT or MR imaging, but dual-energy CT may facilitate a clearer diagnosis."
Kuno, Hirofumi, et al. "Primary staging of laryngeal and hypopharyngeal cancer: CT, MR imaging and dual-energy CT." European journal of radiology 83.1 (2014): e23-e35.

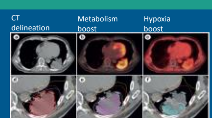
For lung cancer:
"The dual-phase DE-CT examination with a quantification of post-contrast iodine uptake is a promising method for the functional evaluation of mediastinal lymph nodes with lower radiation dose in comparison to volume perfusion CT."
Baxa, Jan, et al. "Dual-phase dual-energy CT in patients with lung cancer: assessment of the additional value of iodine quantification in lymph node therapy response." European radiology 24.8 (2014): 1981-1988.

Images courtesy of Århus University Hospital, Denmark

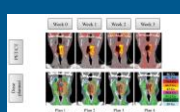
Iodine quantifications with Spectral CT



Iodine map for Dose Painting



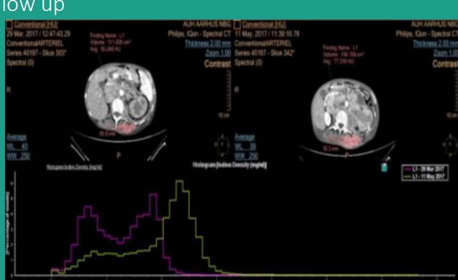
Grootjans, Willem, et al. Nature Reviews Clinical Oncology 12.7 (2015): 395-407.



Adaptive PET seems to be useful for RT, but is impossible in day-today clinic.

Differding, et al., Acta Oncologica 55.2 (2016): 217-225.

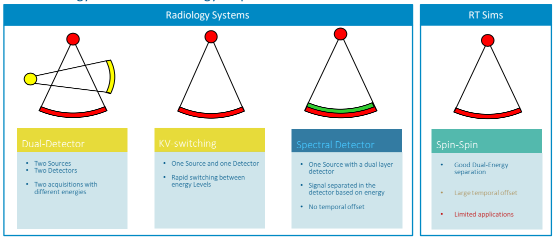
Follow up



Images courtesy of Århus University Hospital, Denmark

Dual energy and Spectral CT

Technology Paths to Dual-Energy Acquisition



What level of Spectral solution is necessary

- Simple spin-spin DECT can only be used to improve proton stopping power calculation
  - **Static features** can be measured (stopping power)
  - **Dynamic features**, like iodine concentrations are problematic
  - **Solving beam hardening** is a mayor issue, due to misalignment
- Only an integrated solution can cater for:
  - Beam-hardening solving
  - Iodine quantification
  - Improved tumour visualisation
  - Easy usuability (adoptation in the clinic)
  - Spectral 4D

What's needed?