Dual-Energy / Spektral-CT: Unterschiedliche Techniken mit vielen Anwendungsmöglichkeiten

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Radiologie; Spitäler Frutigen Meiringen Interlaken AG

USZ Universitäts Spital Zürich

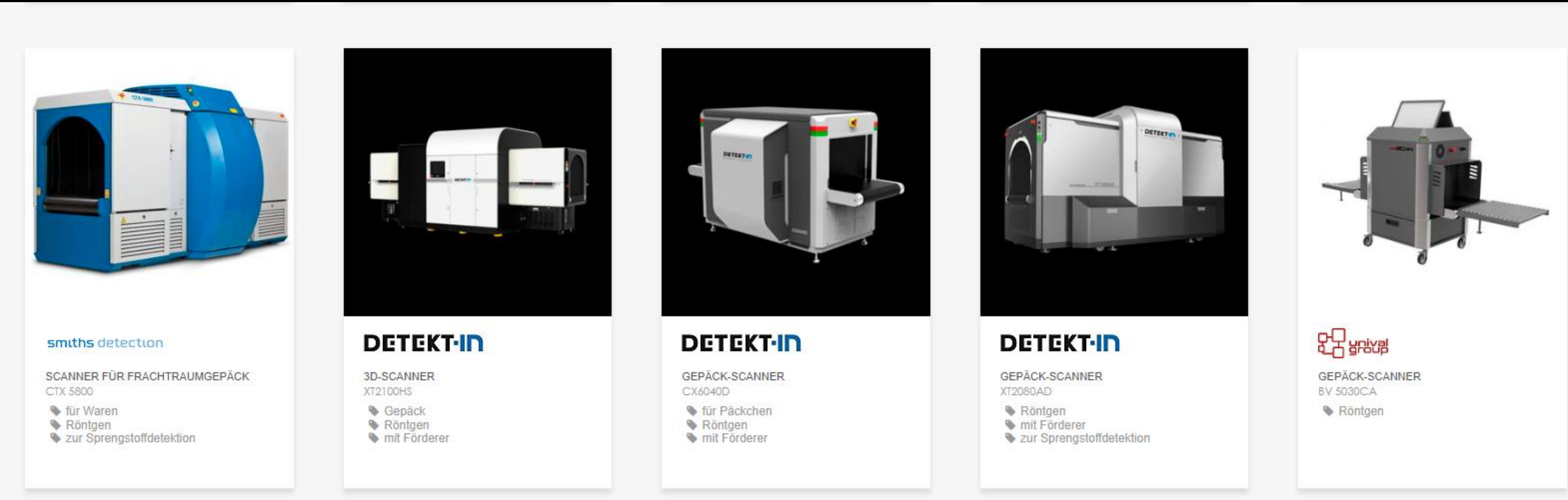
fmi

University of Zurich

Disclosure

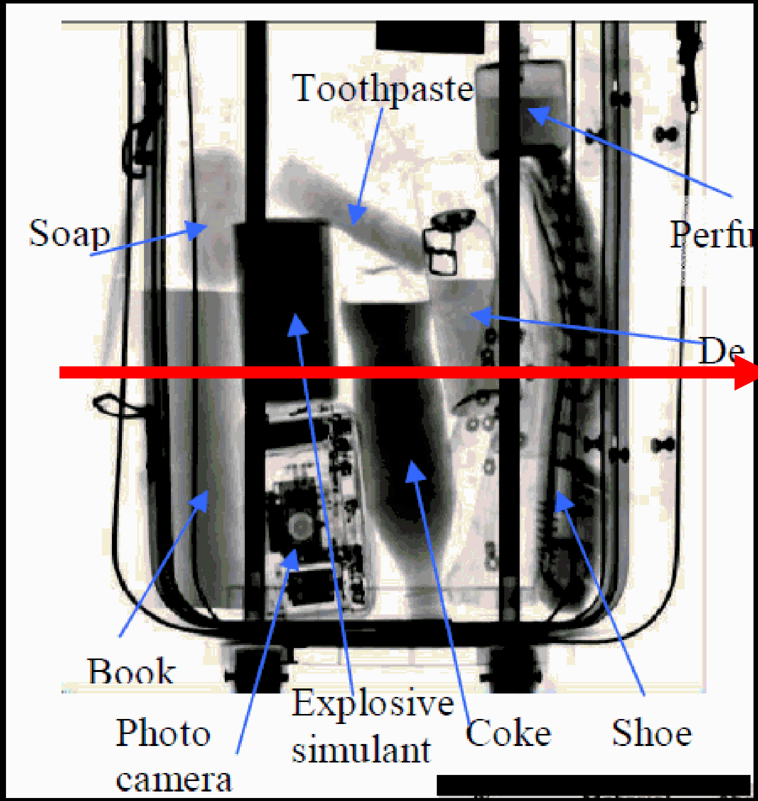
- Siemens: Speaker’s Bureau

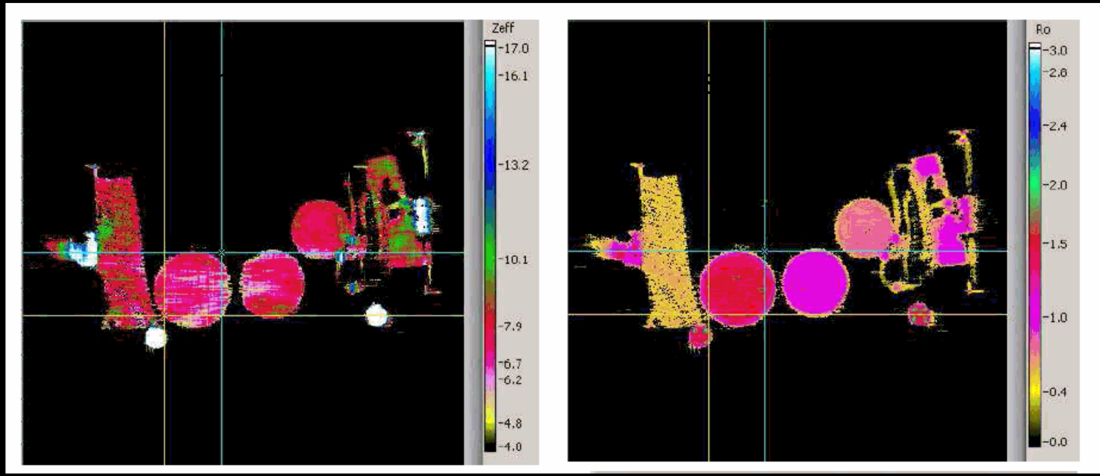
Dual-energy – häufiger als Mann denkt…

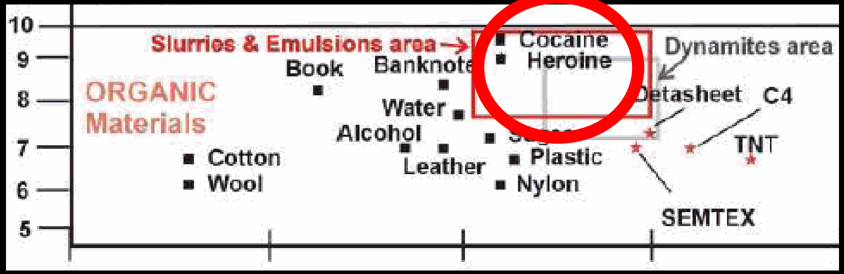


https://www.aeroexpo.online/de/luftfahrt-hersteller/gepaeck-scanner-1314.html

Materialcharakterisierung







Iovea et al, International Symposium on Digital Industrial Radiology and Computed Tomography, 2007, France

Inhalt

- Single-energy versus Dual-energy CT
    - Das Prinzip
- Dual-energy CT
    - Die unterschiedlichen Techniken
    - Die vielen Möglichkeiten und potentielle Anwendungen

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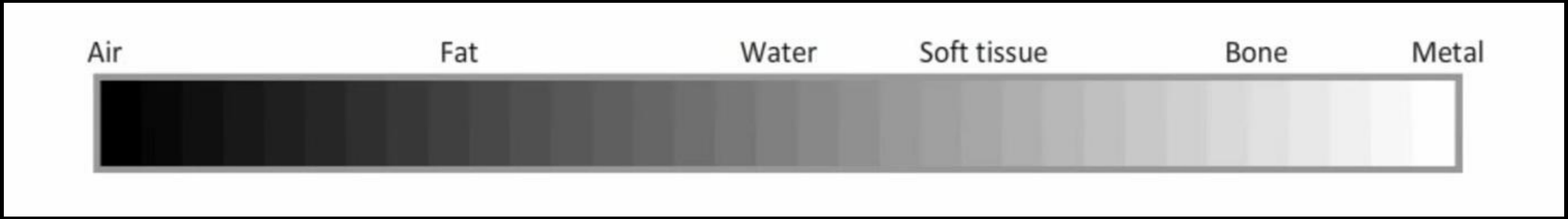
Single-energy CT

Single-energy CT: singuläre Materialcharakterisierung

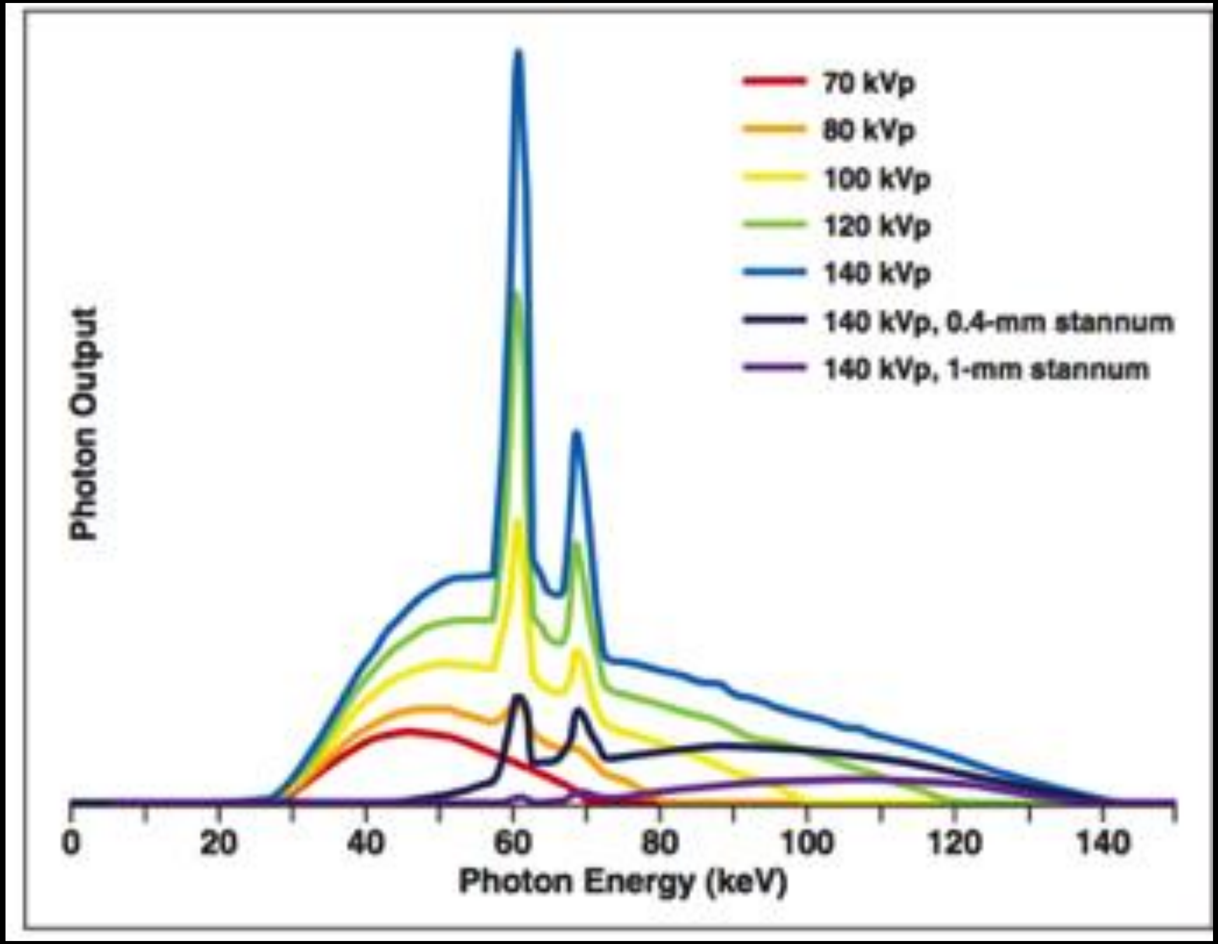
“Wasser”

Alles ist entweder dichter oder weniger dicht als Wasser.



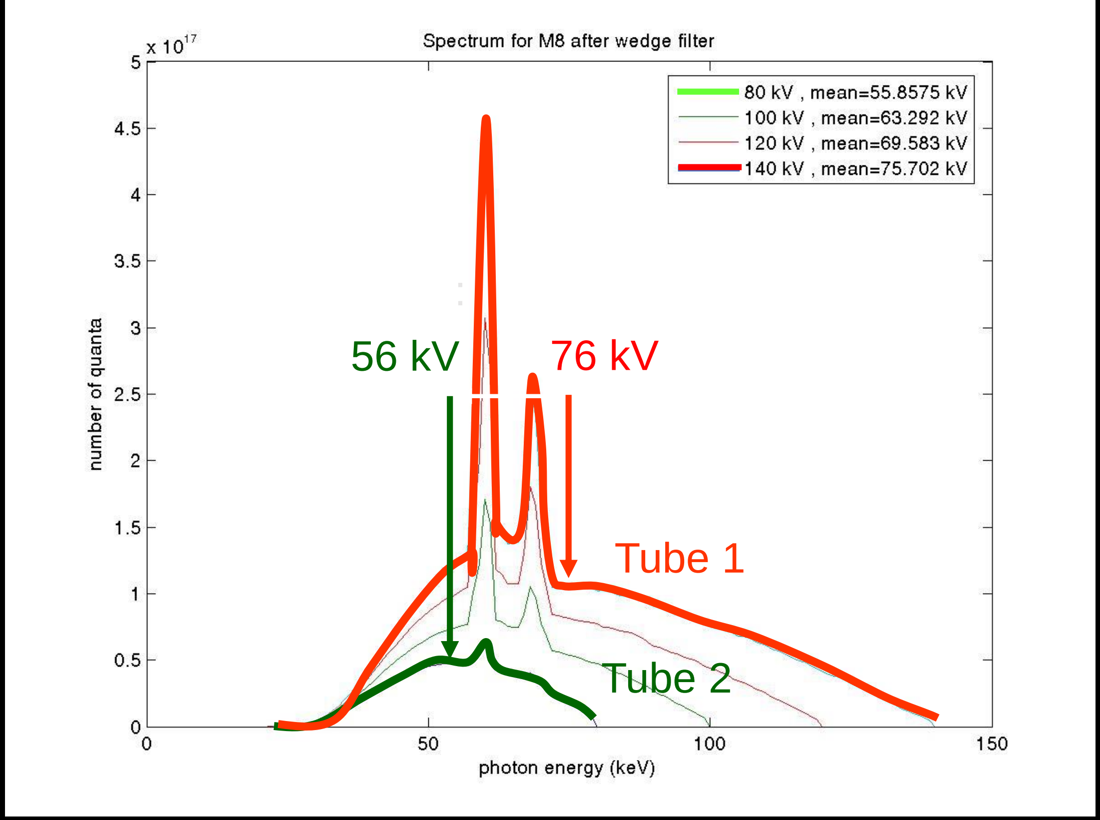
Wikibooks: Basic Physics of Digital Radiography – Kieran Maher et. al.

Energiespektren – Röhrenspannung



Qualität und Quantität

Dual-energy – Zwei Energiespektren



Unterschiedliche Schwächung

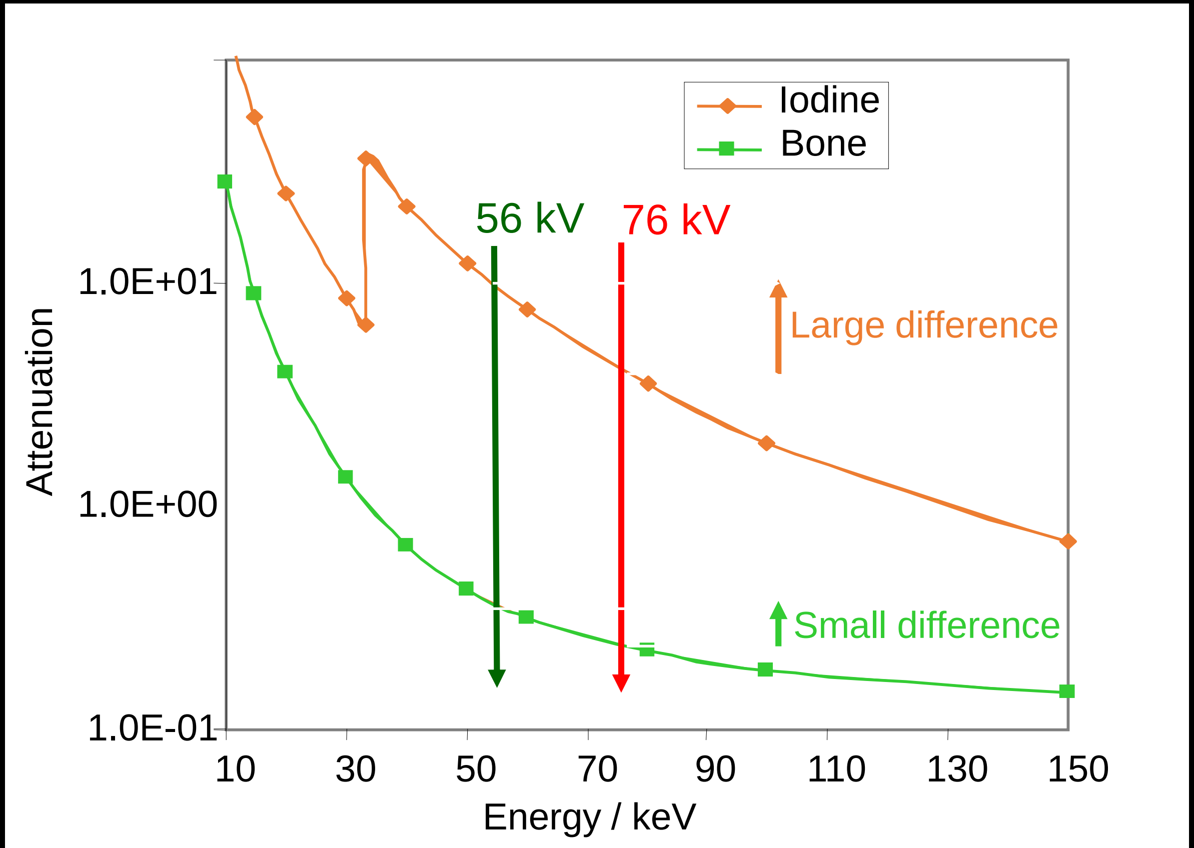
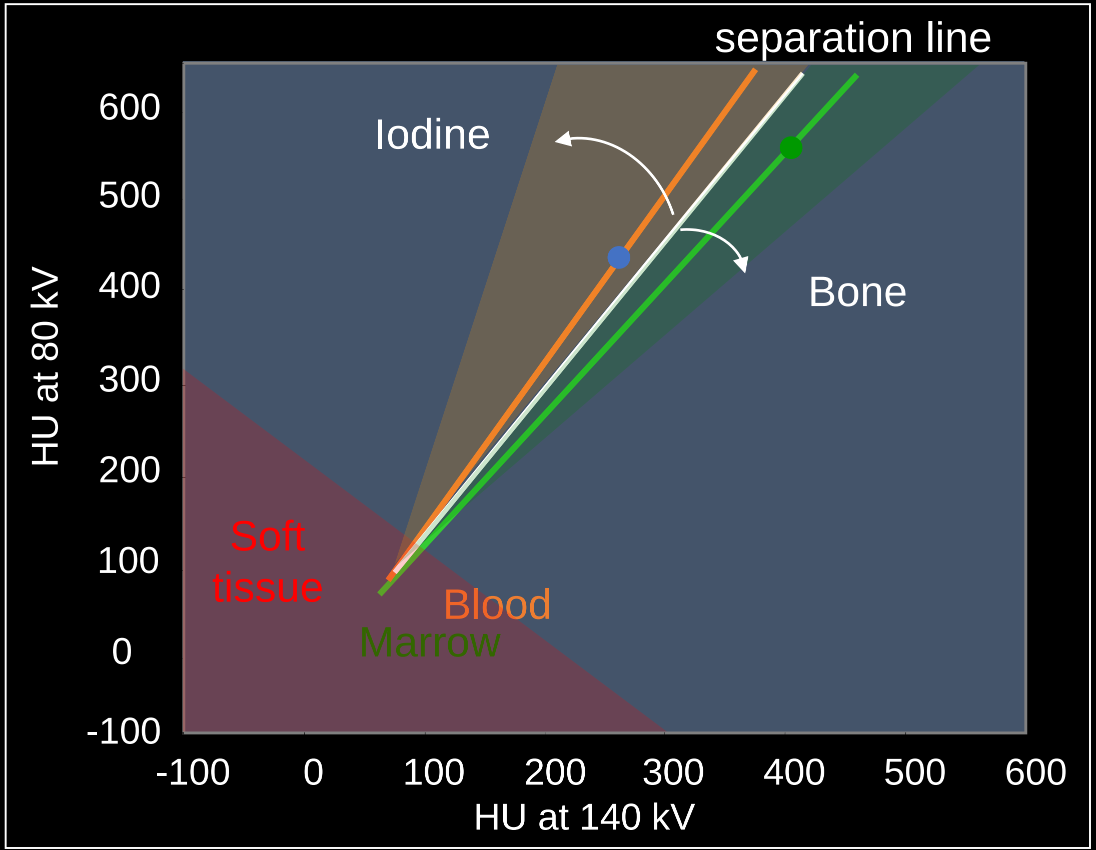


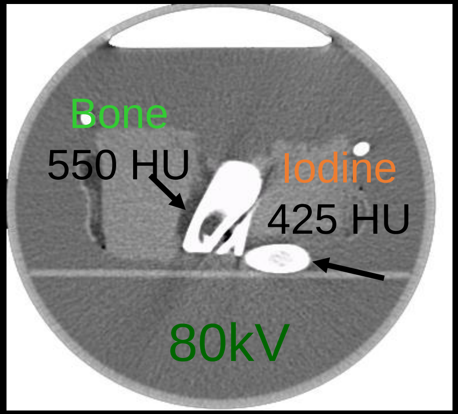
Photo effect ←→ Compton effect

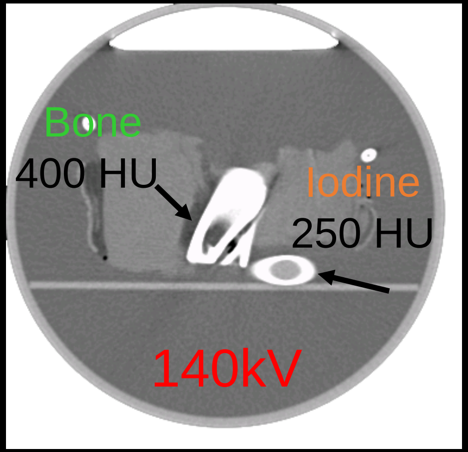
Fletcher JG Radiol Clin N Am 2009

Dual energy – das Prinzip

- Zerlegung von 2-Materialien → z.B. Knochen u. Jod

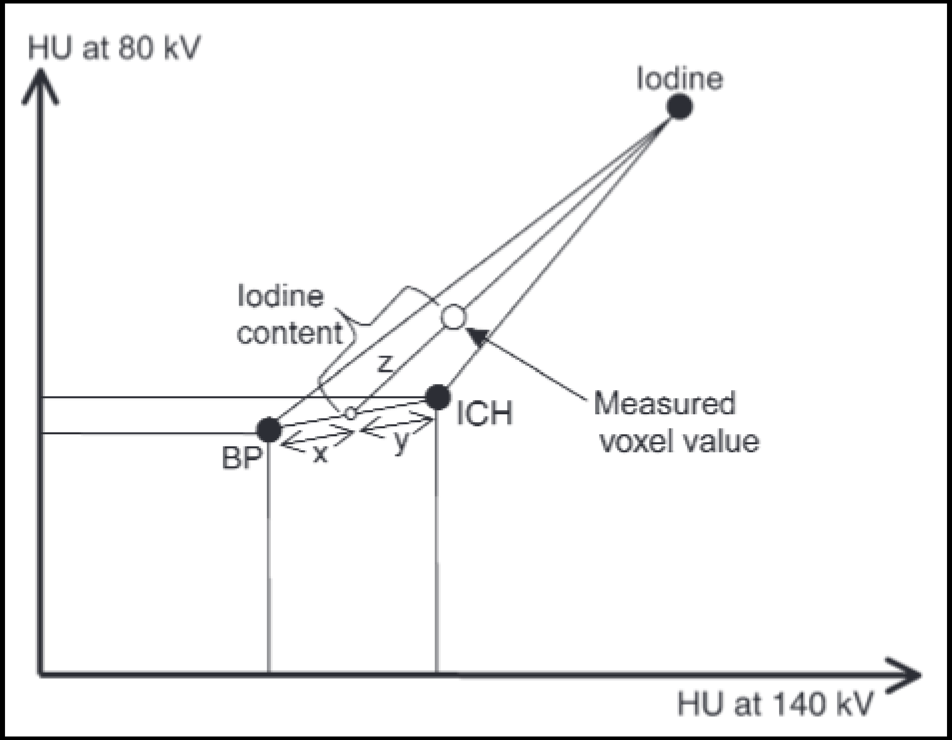






Material decomposition

- 3-Material Dekomposition → Hirnparenchym, Blut und Jod



Gupta R et al., *Radiology 2010;257:205-211*

Inhalt

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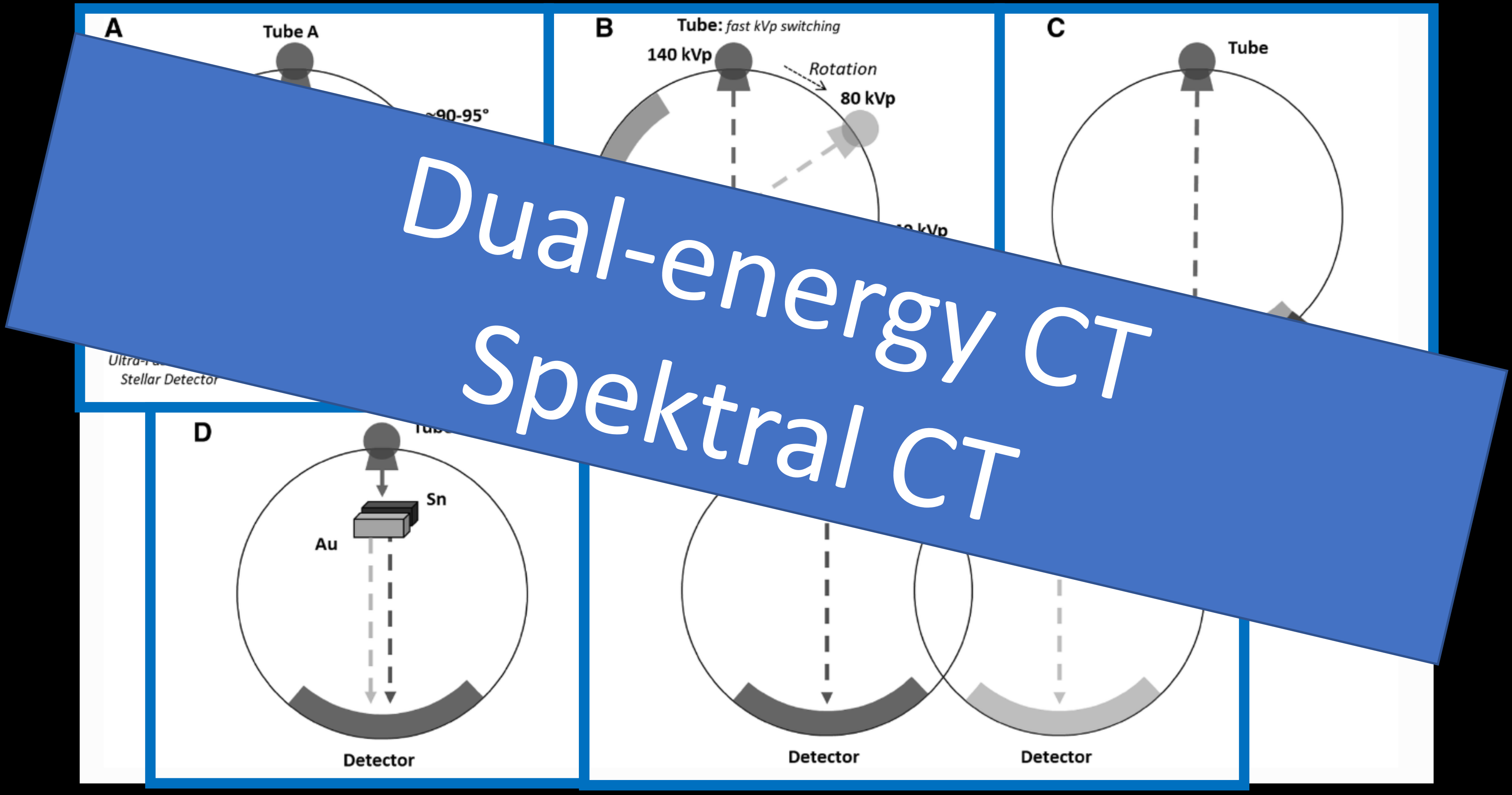
Different approaches



Dual-energy CT
Spektral CT

Agostini et al. La radiologia medica, 2019

Photon-Counting Detector

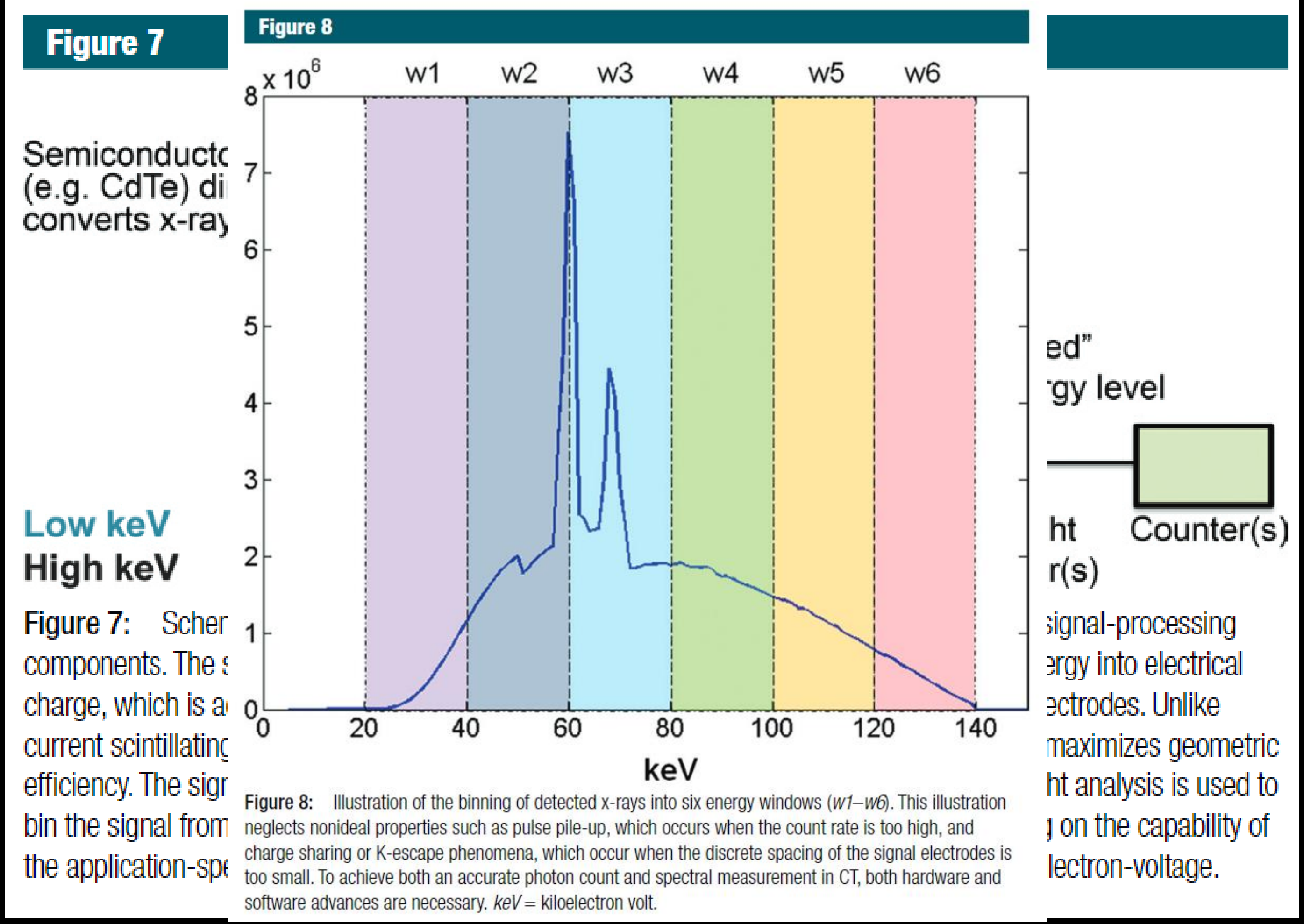


Figure 7: Scher... components. The s... charge, which is a... current scintillating... efficiency. The sign... bin the signal from... the application-spe... signal-processing ...ergy into electrical ...ectrodes. Unlike ...maximizes geometric ...ht analysis is used to ... on the capability of ...lectron-voltage.

Figure 8: Illustration of the binning of detected x-rays into six energy windows (*w1–w6*). This illustration neglects nonideal properties such as pulse pile-up, which occurs when the count rate is too high, and charge sharing or K-escape phenomena, which occur when the discrete spacing of the signal electrodes is too small. To achieve both an accurate photon count and spectral measurement in CT, both hardware and software advances are necessary. *keV* = kiloelectron volt.

Willemink, Radiology 2018

Dual-Energy CT: Radiation Dose Aspects

Conclusion

Of the various methods that have been proposed for acquiring DECT data, image acquisition based on DSCT is the most intensely evaluated approach in the current literature. There is strong evidence that DECT imaging with DSCT is not associated with increased radiation dose levels. Radiation dose data on DECT techniques based on rapid kilovoltage switching to date are inconclusive. Reports on radiation dose with other approaches for DECT data acquisition are scarce or nonexistent, and a conclusive evaluation of the radiation dose associated with these techniques remains elusive. Finally, judicious use of DECT techniques holds the potential of drastically reducing radiation exposure, for example, by the elimination of unnecessary unenhanced CT.

Hensler et al. AJR 2012; 199:S16–S25

Dual-Energy CT of the Abdomen and Pelvis: Radiation Dose Considerations

SA-CME

Joseph R. Grajo, MD[a], Dushyant V. Sahani, MD[b]

Credits awarded for this enduring activity are designated "SA-CME" by the American Board of Radiology (ABR) and qualify toward fulfilling requirements for Maintenance of Certification (MOC) Part II: Lifelong Learning and Self-assessment. To access the SA-CME activity visit http://bit.ly/ACRSACME.

Table 2. Opportunities for Dose Reduction

Potential Dose Reduction Methods
Elimination of phases through acquisition of virtual enhanced images
Advanced iterative reconstruction techniques
Limiting field of view to reduce scatter radiation
Combining dynamic phases of contrast
Individual tailoring of exams to patient body weight to reduce exposure

J Am Coll Radiol 2018;15:1128-1132.

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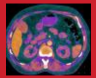
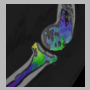
Single-energy

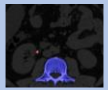
vs

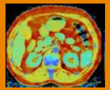
Dual-energy / Spektral-CT


Konventionelles CT
70 - 150kVp

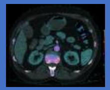

Elektronendichte


Ca-Suppression


Harnsäure


Z eff


VNC


Iod


VMI


Konventionell

Dual-energy / Spektral-CT


VMI


Konventionell

ORIGINAL ARTICLE

High-Pitch Photon-Counting Detector Computed Tomography Angiography of the Aorta

Intraindividual Comparison to Energy-Integrating Detector Computed Tomography at Equal Radiation Dose

André Euler, MD, Kai Higashigaito, MD,* Victor Mergen, MD,* Thomas Sartoretti, BMed,*† Bettina Zanini,* Bernhard Schmidt, PhD,‡ Thomas G. Flohr, PhD,‡ Stefan Ulzheimer, PhD,‡ Matthias Eberhard, MD, EBCR,* and Hatem Alkadhi, MD, MPH, FESER, EBCR**

- 40 Patienten eingeschlossen, CTA an einem EID-CT (Somatom Force) und einem Photon-counting CT (Naeotom alpha)
- Gleiche Strahlendosis: CTDIvol 2.68 ± 1.33 mGy für EID-CT und 2.63 ± 1.3 mGy für Photon-counting CT

TABLE 1. CT Scan Parameters

CT Parameter	EID-CT	PCD-CT
Detector collimation, mm	192 × 0.6 = 115.2 (z-flying focal spot)	144 × 0.4 = 57.6
Tube voltage, kV	ATVS (ref. 100 kV)	120
Tube current (reference tube current time product for EID-CT and IQ for PCD-CT)	Ref. mAs = 162	IQ = 58
Gantry rotation time, s	0.25	0.25
Pitch	3.2	3.2

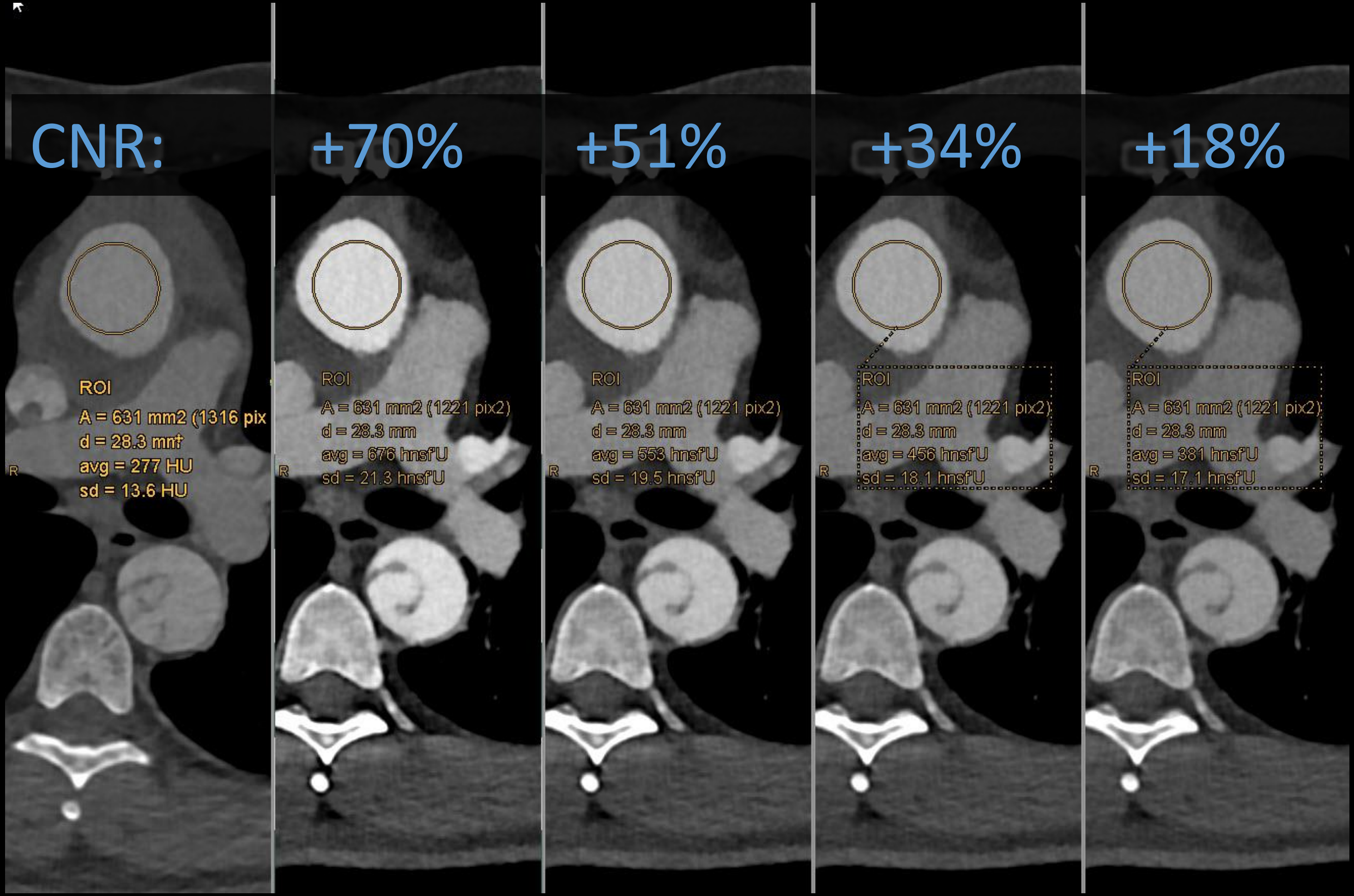
VMI

Invest Radiol 2022;57:115-121

VMI

CTA der Aorta – high pitch

100 kVp	40 keV	45 keV	50 keV	55 keV
$CTDI_{vol}$ 3.93	$CTDI_{vol}$ 3.93	$CTDI_{vol}$ 3.93	$CTDI_{vol}$ 3.93	$CTDI_{vol}$ 3.93



FORCE	NAEOTOM	NAEOTOM	NAEOTOM	NAEOTOM

Invest Radiol 2022;57:115-121

VMI

CTA der Aorta – high pitch

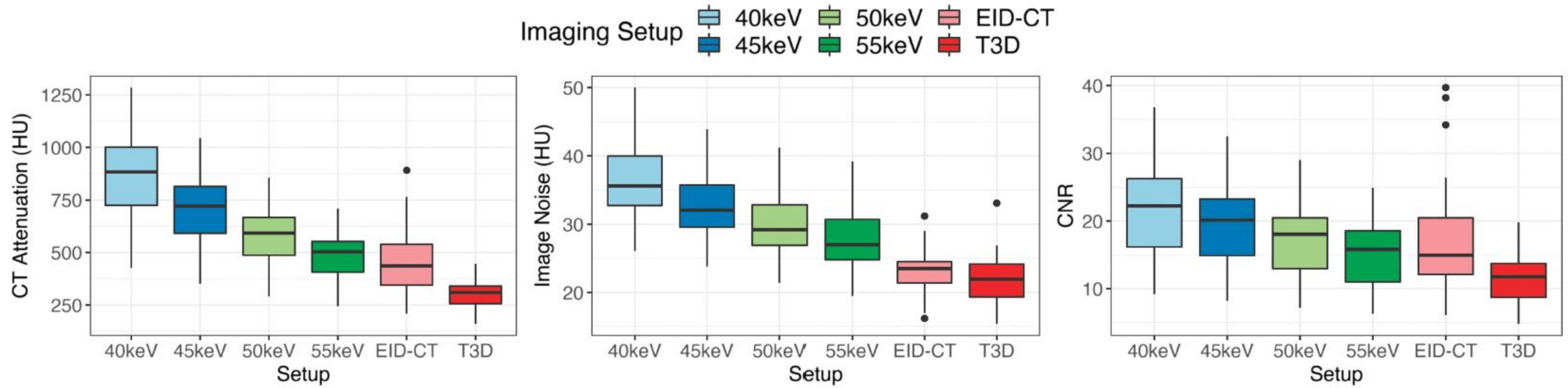


FIGURE 1. Computed tomography (CT) attenuation of the aorta, image noise, and contrast-to-noise ratio as a function of imaging setup. Box and whisker plots demonstrate increasing mean CT attenuation of the aorta, contrast-to-noise ratio (CNR), and noise with decreasing keV level.

Invest Radiol 2022;57:115-121

Epikardiales Fettgewebe

Epicardial Adipose Tissue Attenuation and Fat Attenuation Index: Phantom Study and In Vivo Measurements With Photon-Counting Detector CT

Victor Mergen, MD[1], Emanuel Ried, MD[1], Thomas Allmendinger, PhD[2], Thomas Sartoretti, BMed[1], Kai Higashigaito, MD[1], Robert Manka, MD[1,3], Andre Euler, MD[1], Hatem Alkadhi, MD, MPH[1], Matthias Eberhard, MD[1]

Cardiothoracic Imaging · Original Research

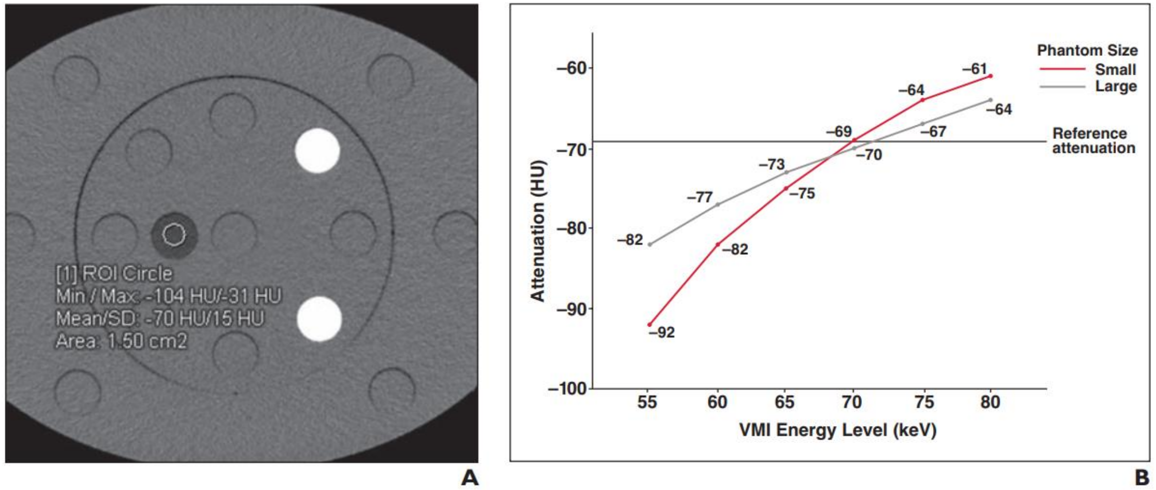
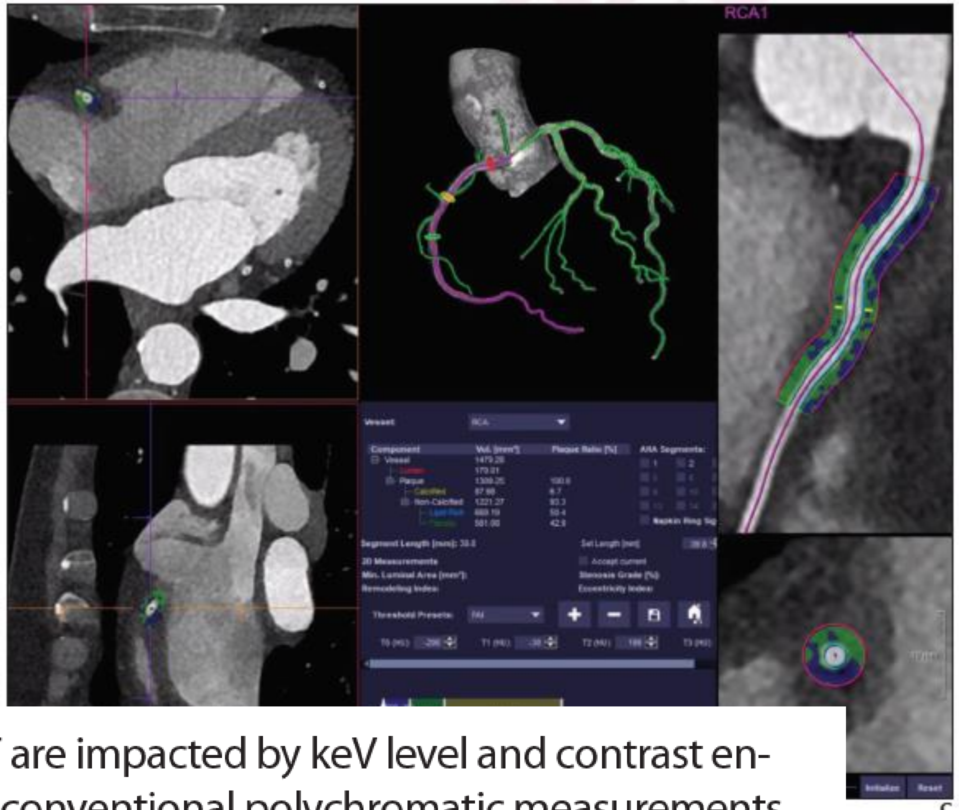


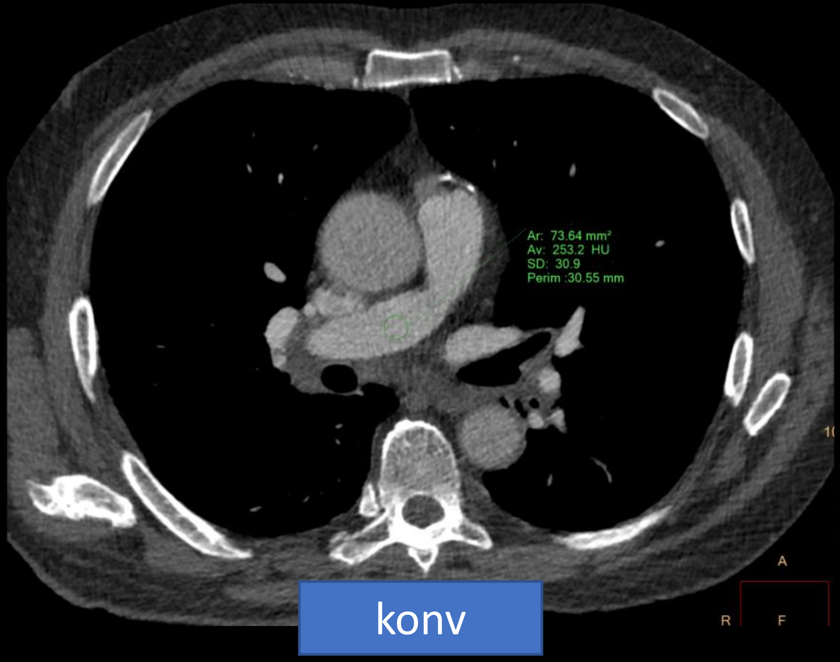
Fig. 1—Measurement of attenuation in phantom fat insert.
A, Photon-counting detector (PCD) CT image of large phantom (using extension ring measuring 20 × 40 cm) shows ROI placement in fat insert. PCD CT images of phantom were reconstructed using quantum iterative reconstruction 3 and quantitative reconstruction kernel Qr44.
B, Graph shows attenuation values of fat insert in relation to energy level. Horizontal reference line represents attenuation of fat insert determined on energy-integrating detector CT (–69 HU). VMI = virtual monoenergetic image.

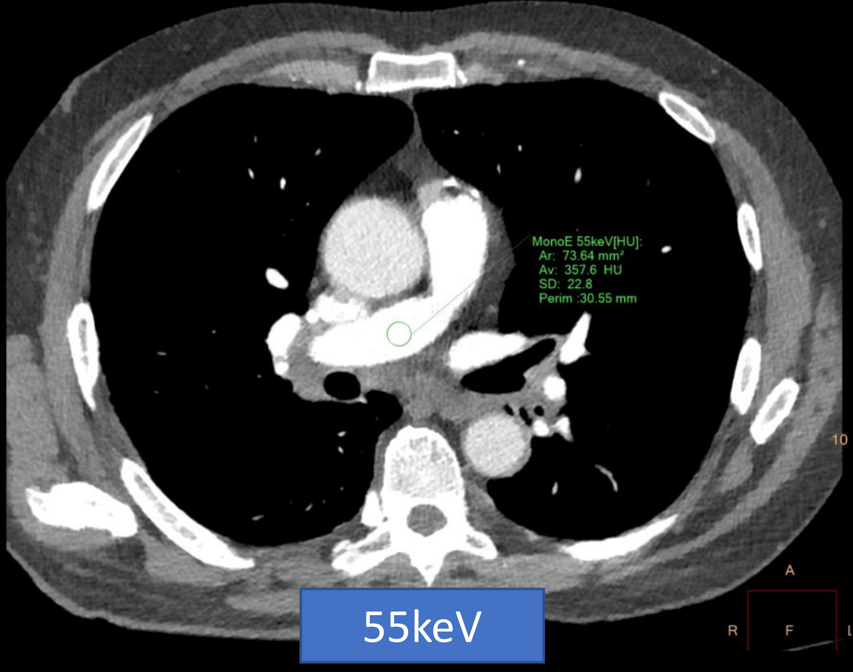


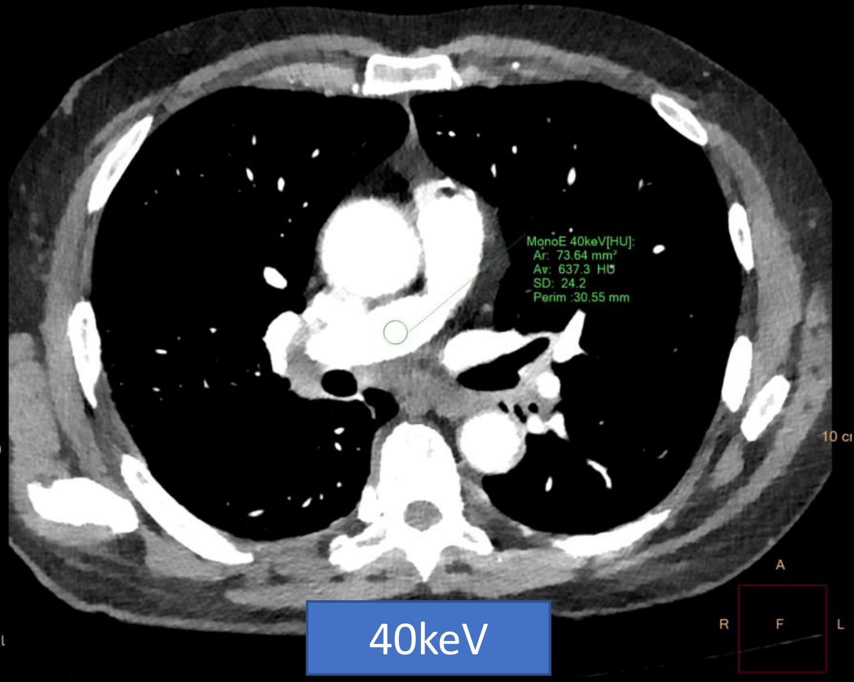
Conclusion: EAT attenuation and FAI measurements using PCD CT are impacted by keV level and contrast enhancement. Use of 70 keV provides fat attenuation approximating conventional polychromatic measurements.

Real-life - Lungenembolie

Kontrastmittel		
Optiray 370	ml	Flow
KM	30	3
NaCl	50	3







Metall-Artefaktreduktion

VMI ↑

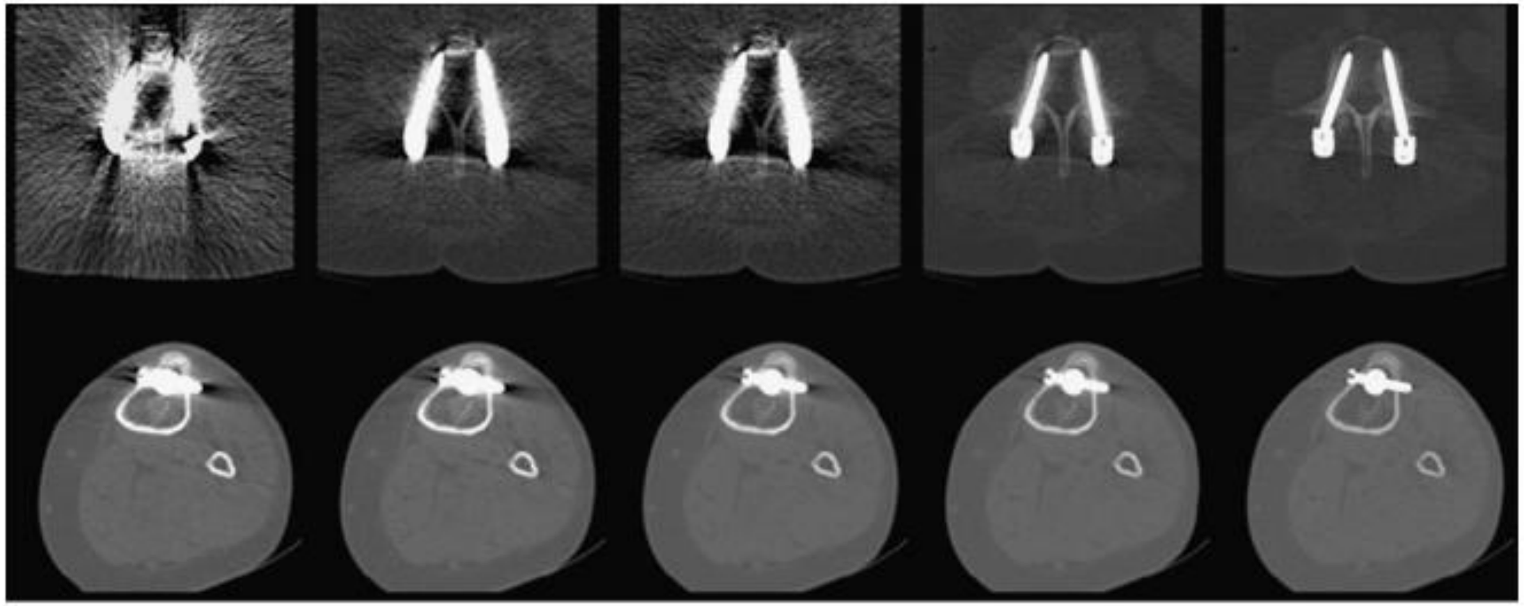
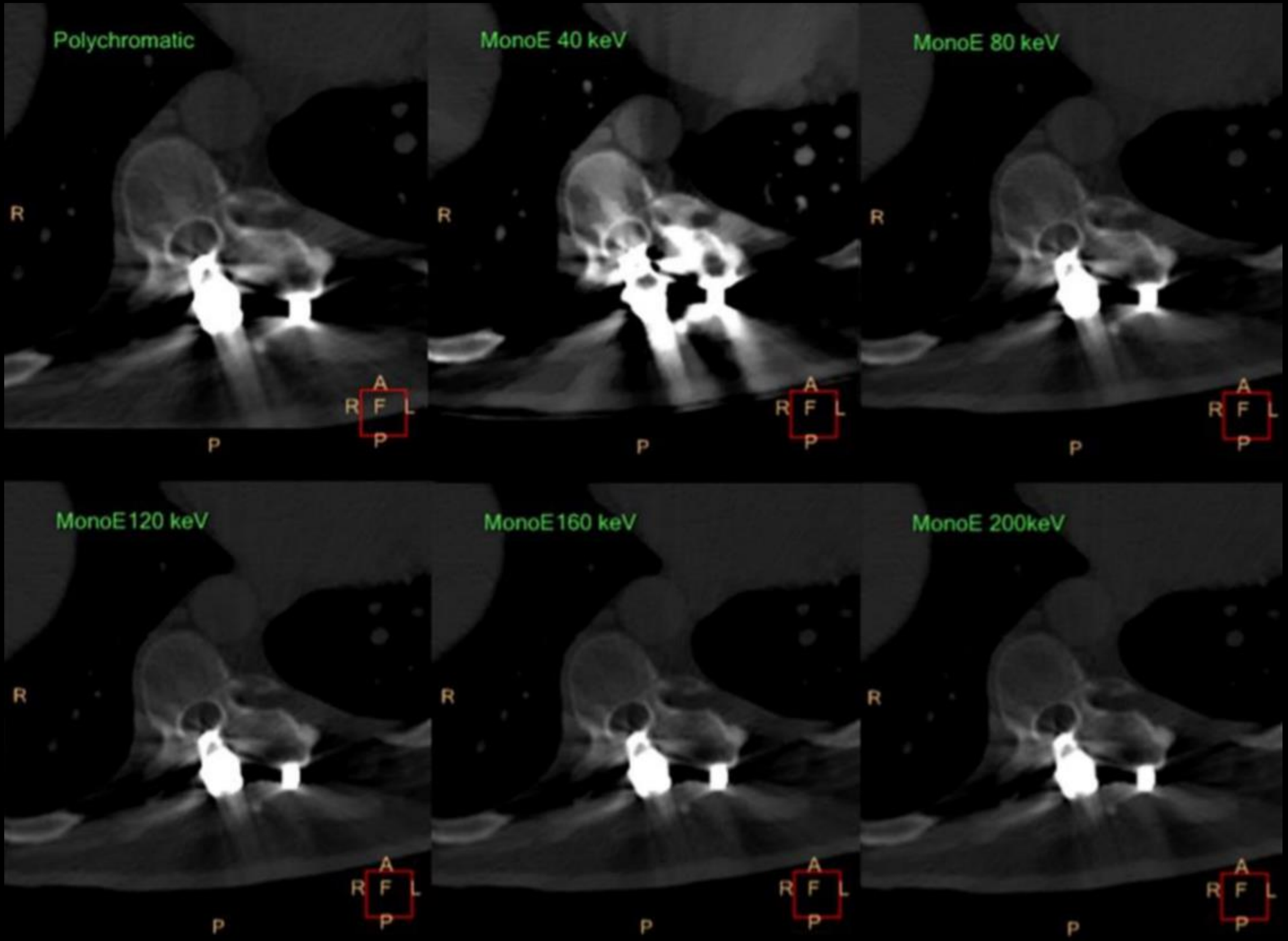


Fig. 1 Two sets of images showing screws in the spine and in the tibia reconstructed at 64, 69, 88, 105 and an optimal keV setting (left to right). Note that the spinal canal the thin layer of bone covering the left screw are only discernible in the two reconstructions at the highest energy. Similarly, the screw in the tibia is optimally depicted in the rightmost image

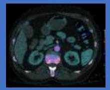
Bamberg F et al. Eur Radiol 2011

Metall-Artefaktreduktion



Kosmas et al.Skel Radiol 2019

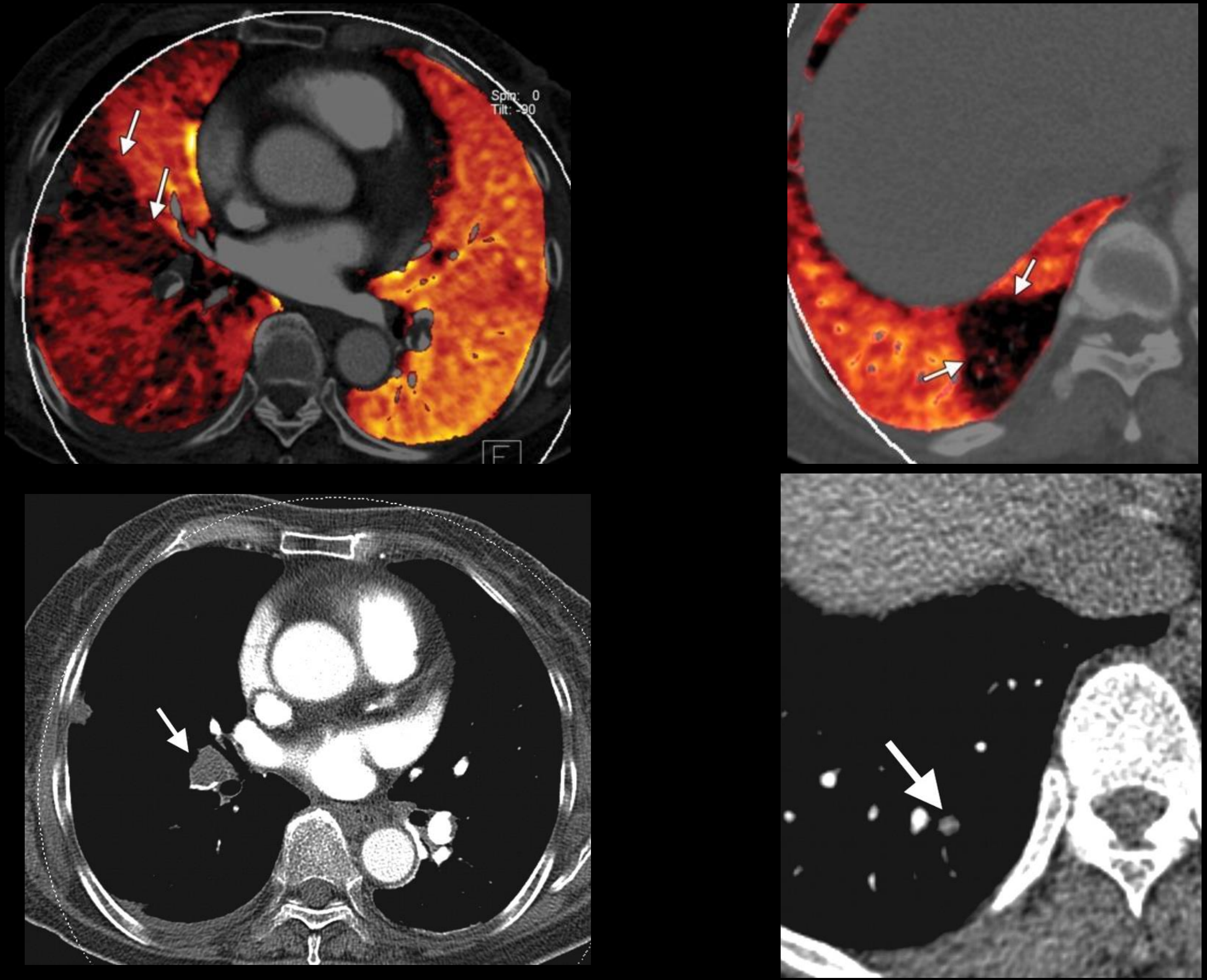
Dual-energy / Spektral-CT


Iod


VMI

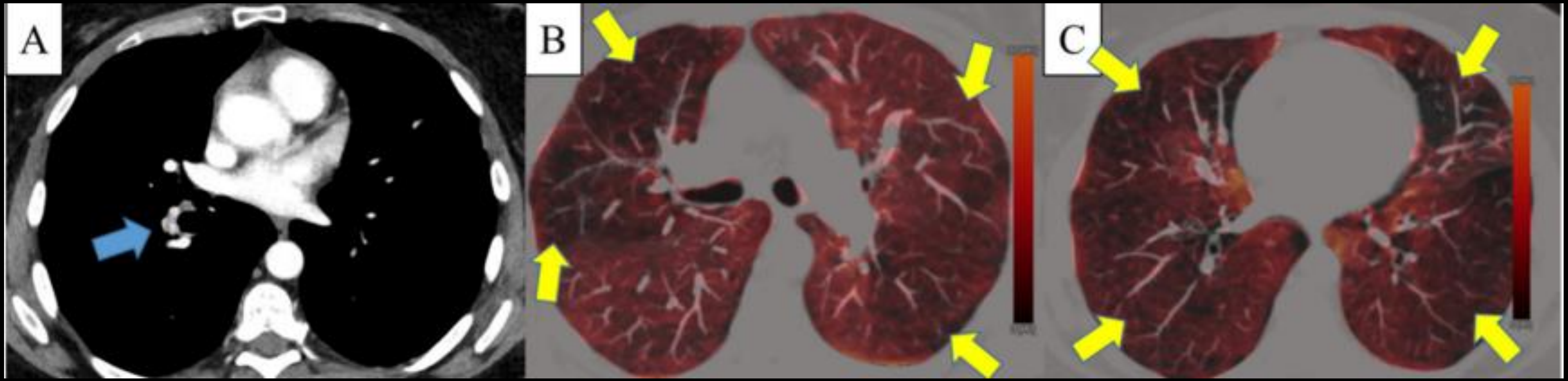

Konventionell

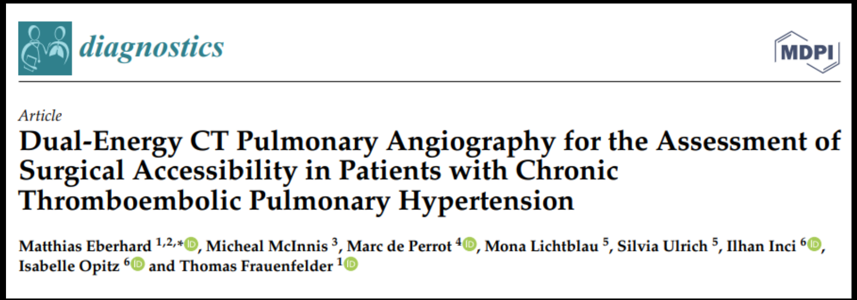
Lungen-Perfusion



Kang M et al. Radiographics 2010;30:685-698

Lungen-Perfusion




diagnostics

MDPI

Article

Dual-Energy CT Pulmonary Angiography for the Assessment of Surgical Accessibility in Patients with Chronic Thromboembolic Pulmonary Hypertension

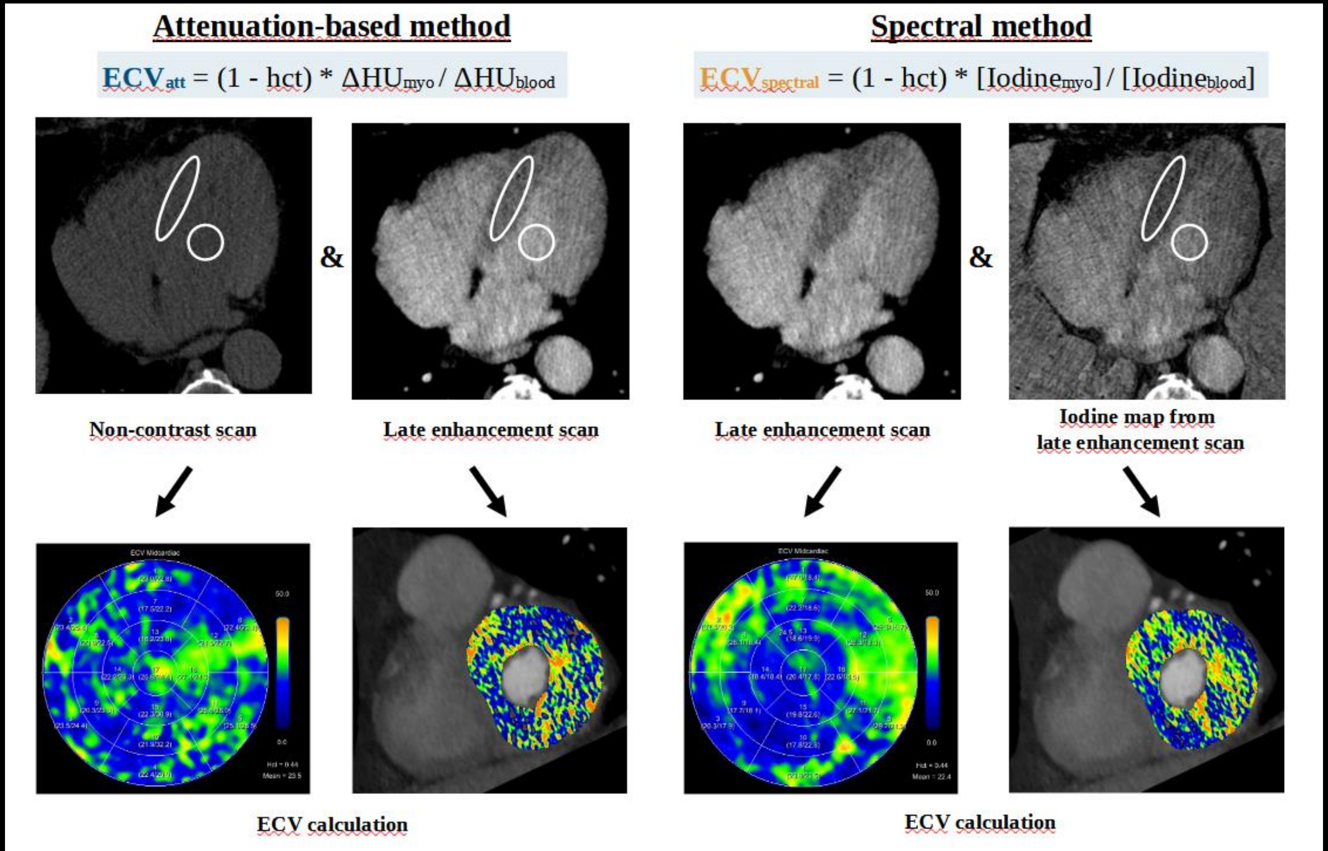
Matthias Eberhard [1,2,*], Micheal McInnis [3], Marc de Perrot [4], Mona Lichtblau [5], Silvia Ulrich [5], Ilhan Inci [6], Isabelle Opitz [6] and Thomas Frauenfelder [1]

Myokardiales late enhancement

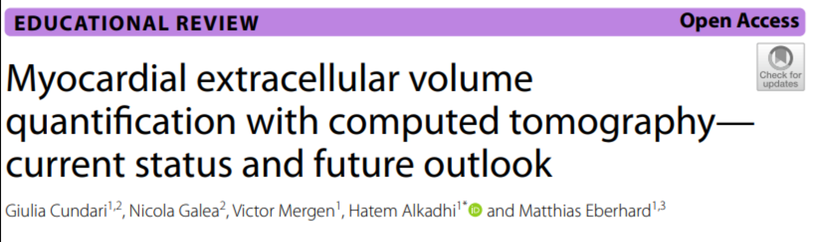
EDUCATIONAL REVIEW Open Access

Myocardial extracellular volume quantification with computed tomography—current status and future outlook

Giulia Cundari[1,2], Nicola Galea[2], Victor Mergen[1], Hatem Alkadhi[1*] and Matthias Eberhard[1,3]

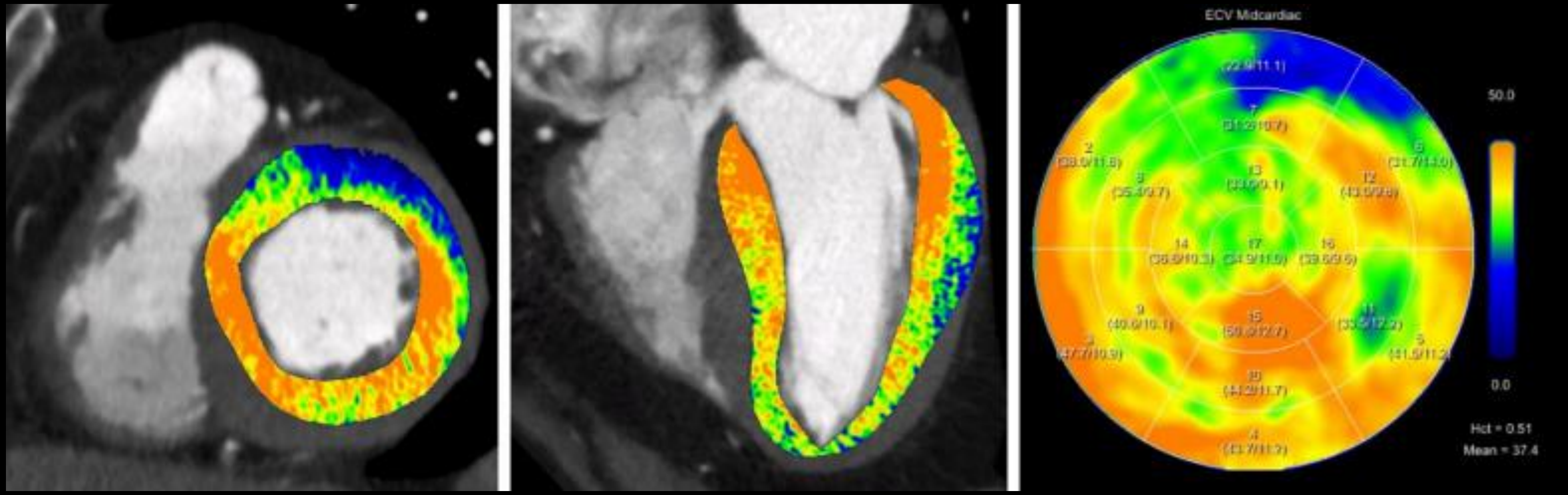


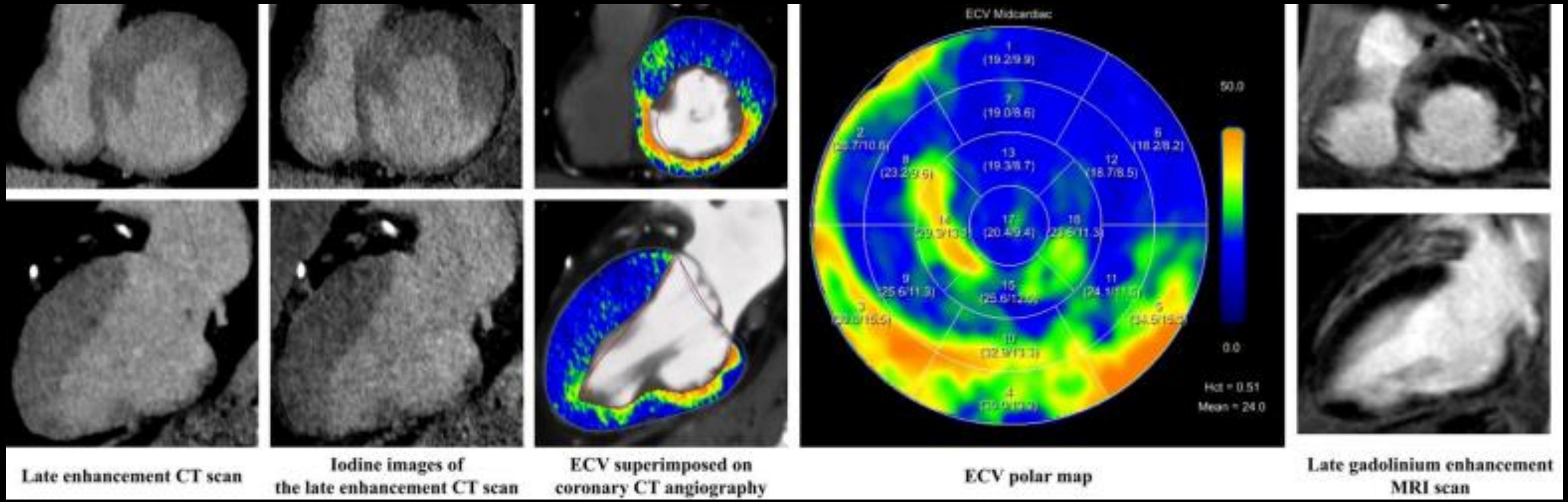
Myokardiales late enhancement


EDUCATIONAL REVIEW Open Access

Myocardial extracellular volume quantification with computed tomography—current status and future outlook

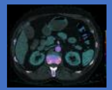
Giulia Cundari[1,2], Nicola Galea[2], Victor Mergen[1], Hatem Alkadhi[1*] and Matthias Eberhard[1,3]





Dual-energy / Spektral-CT

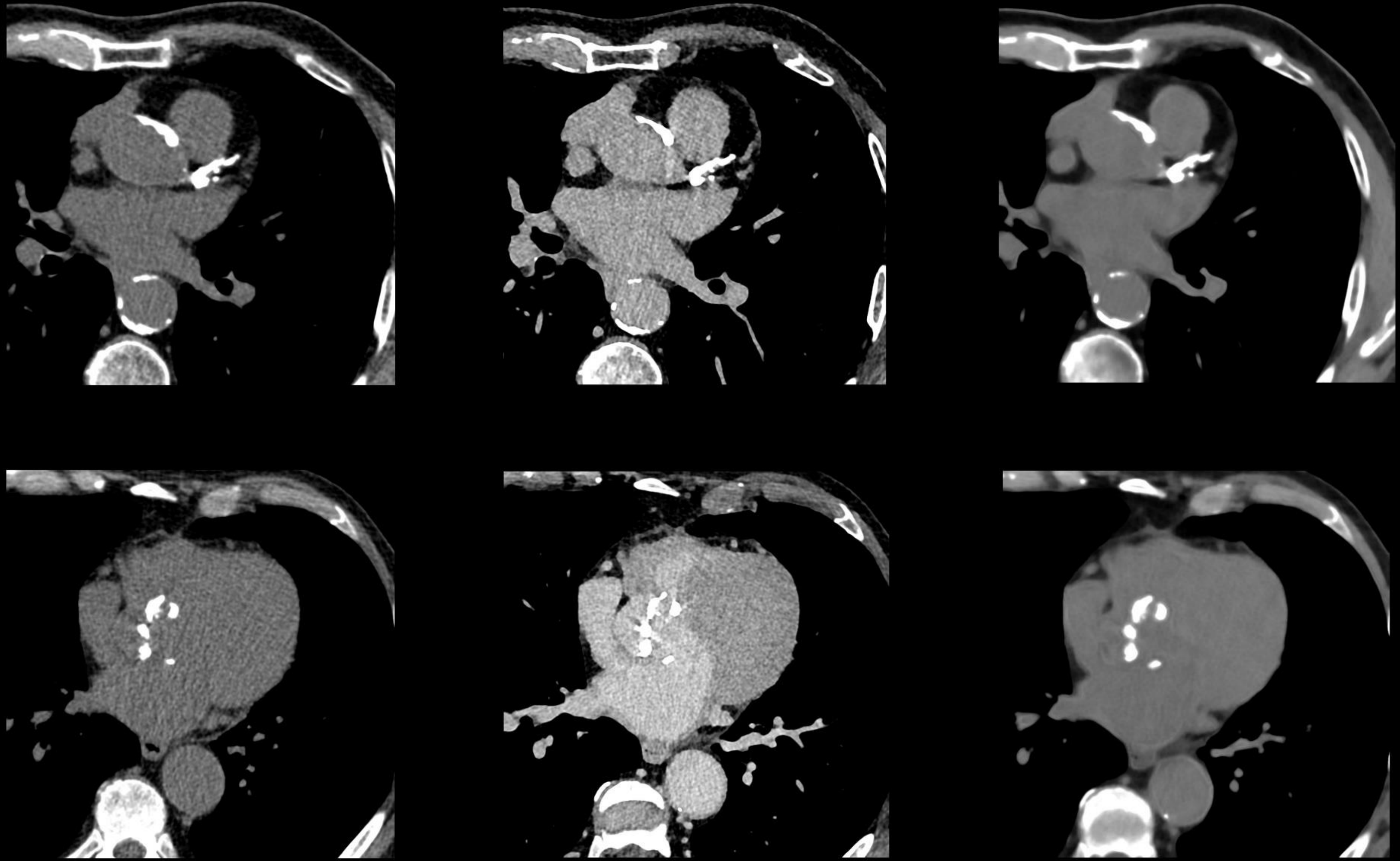
 VNC

 Iod

 VMI

 Konventionell

Pure Calcium – Dual-energy-basierte Iod-Subtraktion



VNC

TNC

LE

VNI

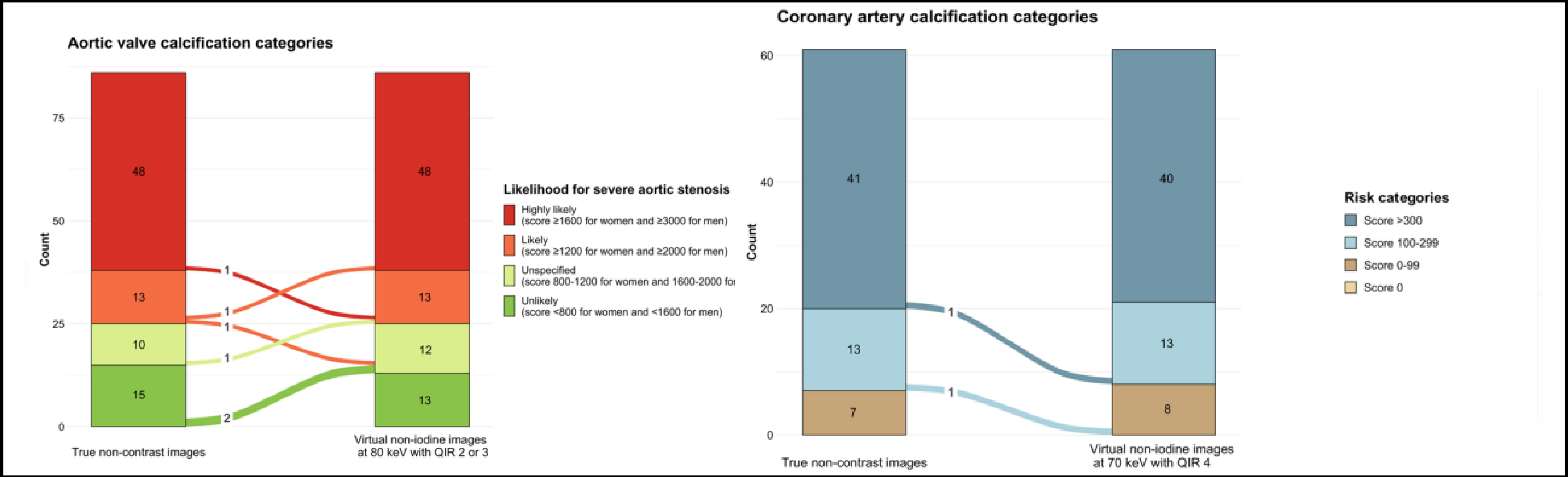
Radiology: Cardiothoracic Imaging

ORIGINAL RESEARCH

Cardiac Virtual Noncontrast Images for Calcium Quantification with Photon-counting Detector CT

Victor Mergen, MD • Sadaf Ghouse, BMed • Thomas Sartoretti, BMed • Robert Manka, MD • André Euler, MD • Albert M. Kasel, MD • Hatem Alkadhi, MD, MPH, EBCR • Matthias Eberhard, MD, EBCR

Pure Calcium – Dual-energy-basierte Iod-Subtraktion



VNC

Radiology: Cardiothoracic Imaging ORIGINAL RESEARCH

Cardiac Virtual Noncontrast Images for Calcium Quantification with Photon-counting Detector CT

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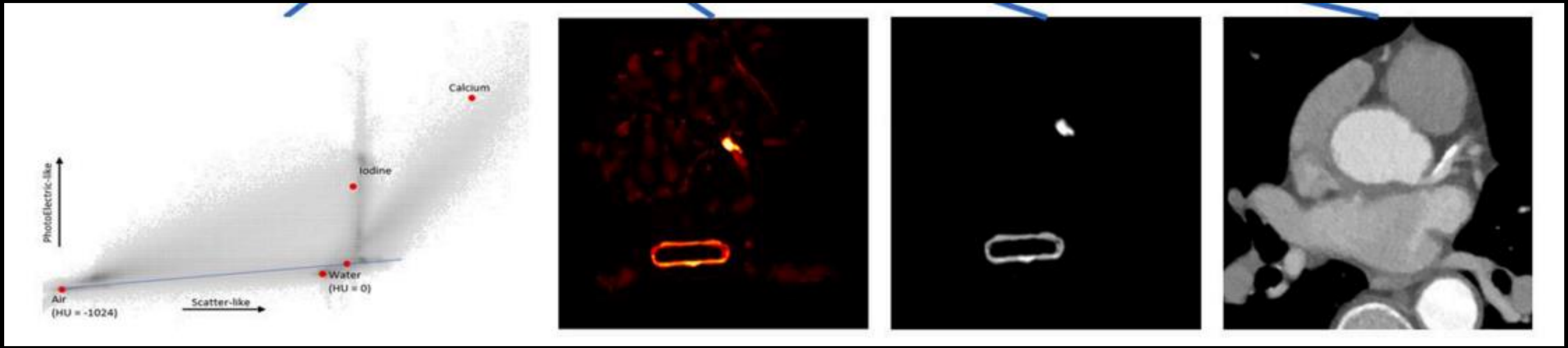
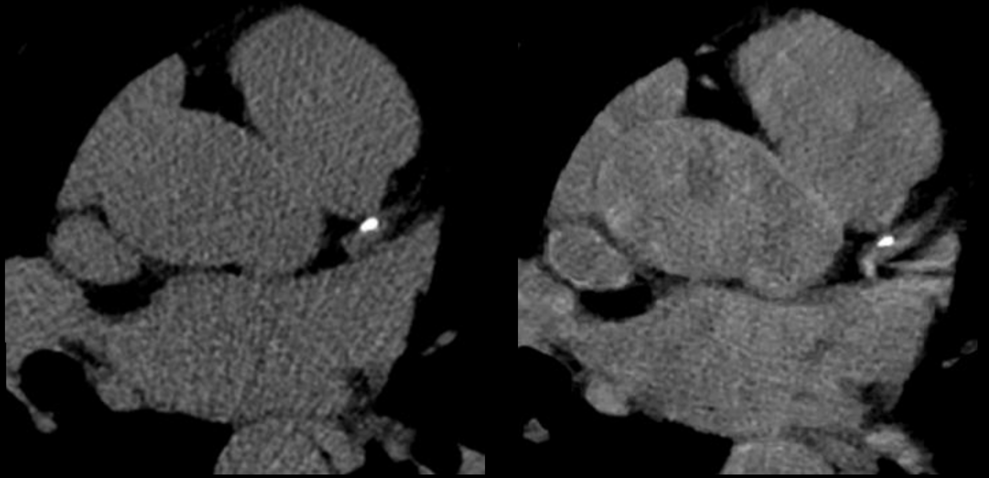
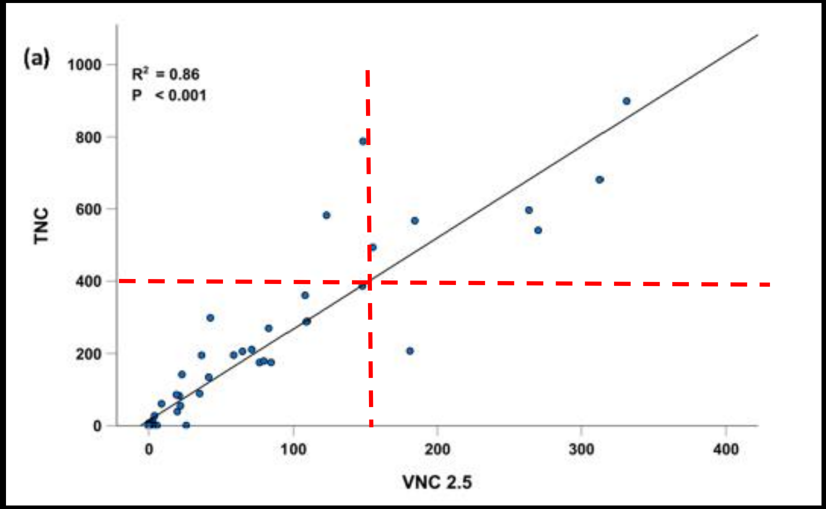
VNC

Coronary calcium scoring using virtual non-contrast reconstructions on a dual-layer spectral CT system: Feasibility in the clinical practice

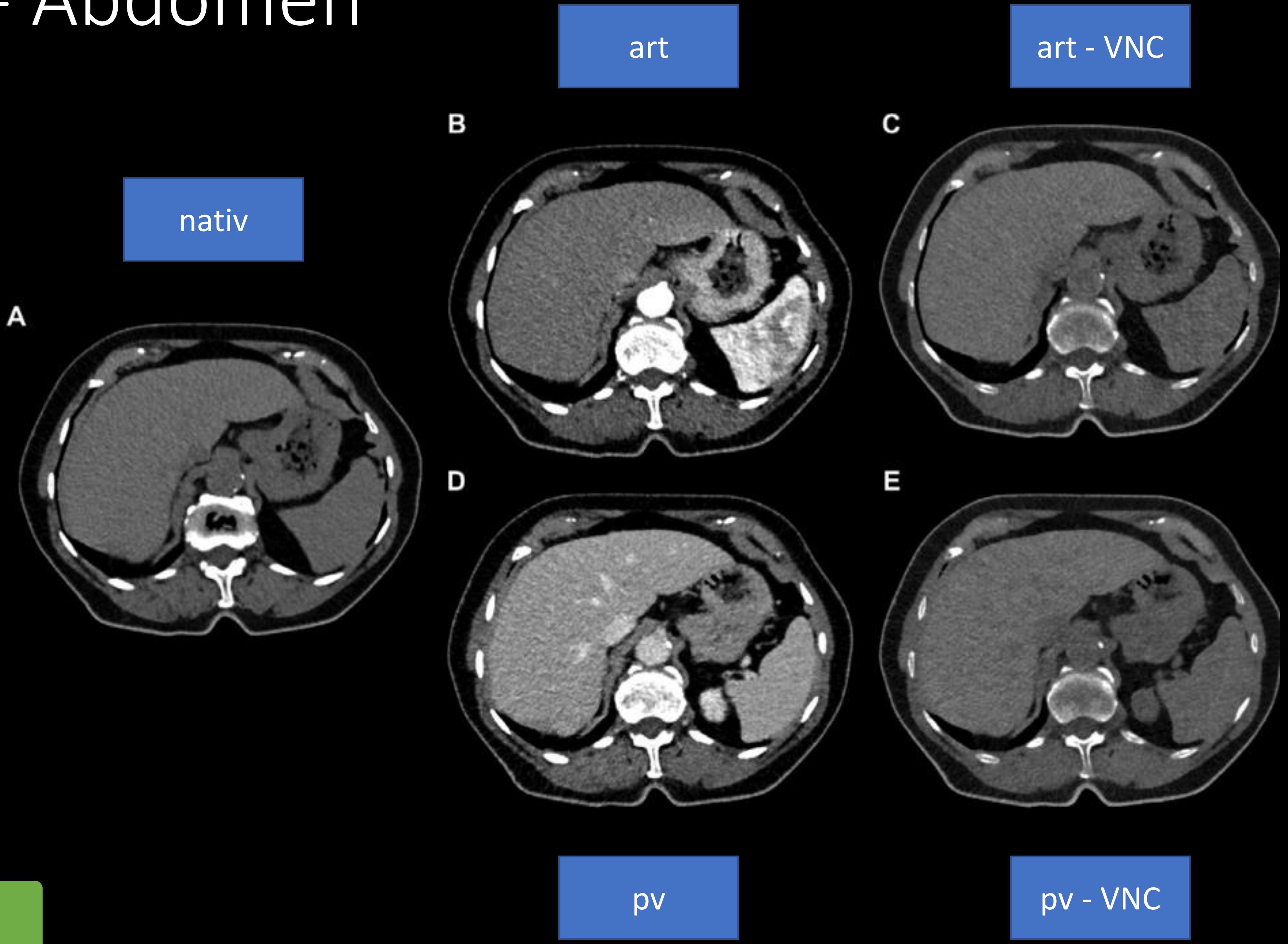
I.L. Langenbach [a,b,*], H. Wienemann [c], K. Klein [a], J.E. Scholtz [d], L. Pennig [a], E. Langzam [e], G. Pahn [f], J.A. Holz [g], D. Maintz [a], C.P. Naehle [a,h], M.C. Langenbach [a,b]







VNC - Abdomen



Mergen V et al. Radiology 2022

Jodsubtraktion – *virtuell* native Bilder

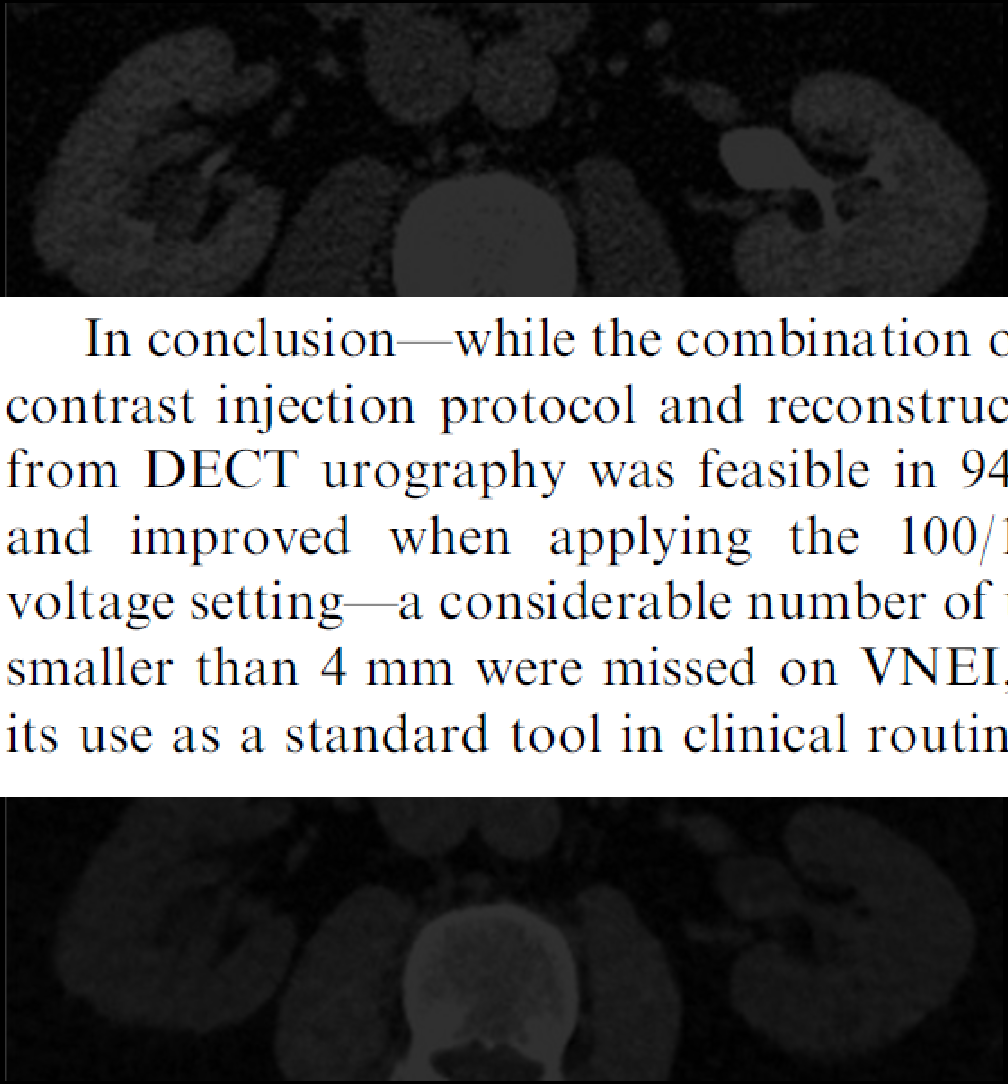
Split-bolus CT
dual-energy

standard
nativ

virtuell
nativ

Karlo C et al., Abdom Imaging 2013; 38:1136-43

Jodsubtraktion – *virtuell* native Bilder



Split-bolus CT
dual-energy

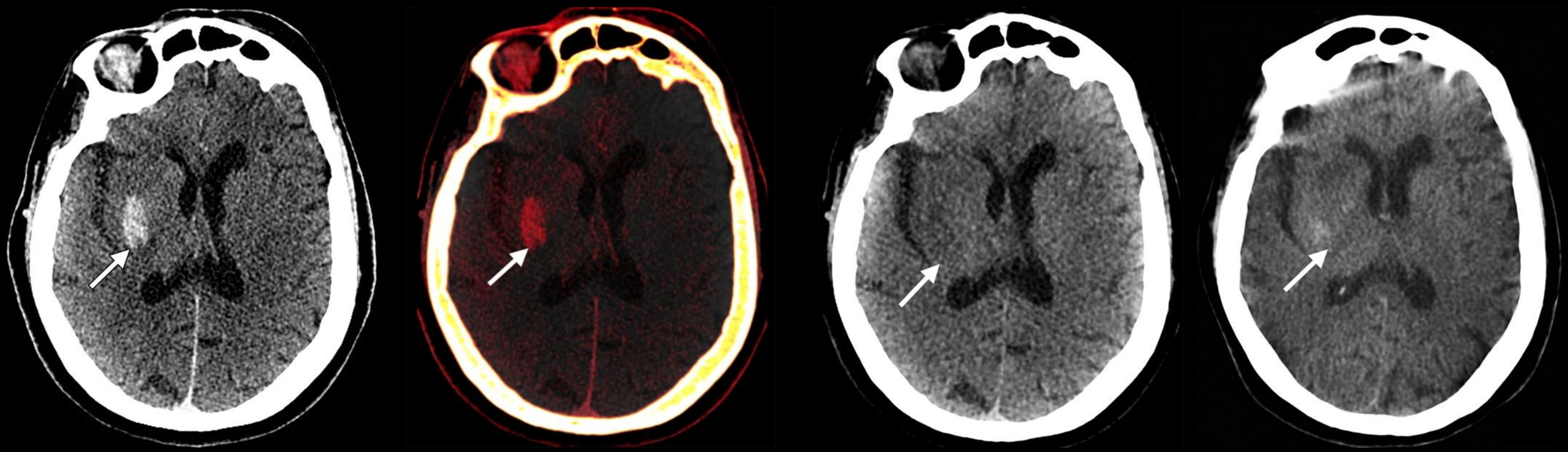
In conclusion—while the combination of a split-bolus contrast injection protocol and reconstruction of VNEI from DECT urography was feasible in 94% of patients and improved when applying the 100/140 kVp tube voltage setting—a considerable number of urinary stones smaller than 4 mm were missed on VNEI, thus limiting its use as a standard tool in clinical routine.

virtuell
nativ

Karlo C et al., Abdom Imaging 2013; 38:1136-43

dual-energy CT: Unterscheidung *Jod vs Blut*

Schädel CT 30 min. nach i.a. Lyse (mit i.a. KM-Gabe)



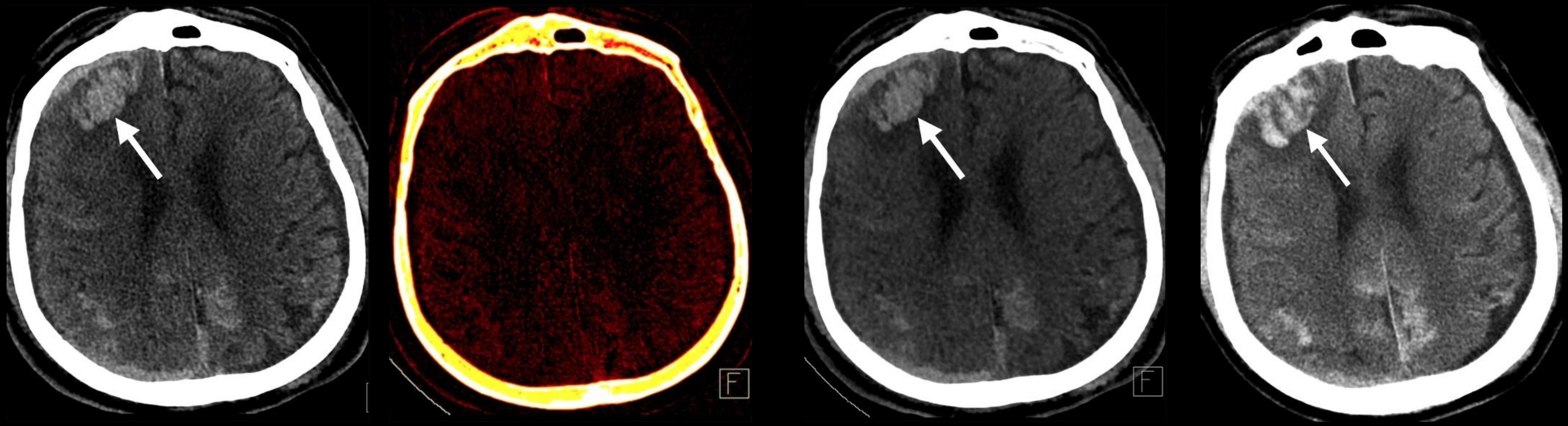
standard CT | Jodbild | virtuell nativ | *follow-up*

= Jodextravasation

Gupta R et al., *Radiology 2010;257:205-211*

dual-energy CT: Unterscheidung *Jod vs Blut*

Schädel CT 30 min. nach i.a. Lyse (mit i.a. KM-Gabe)

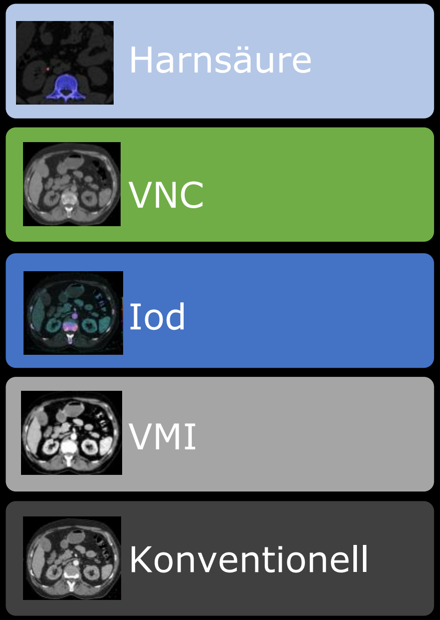


standard CT | Jodbild | virtuell nativ | *follow-up*

= Einblutung

Gupta R et al., *Radiology 2010;257:205-211*

Dual-energy / Spektral-CT

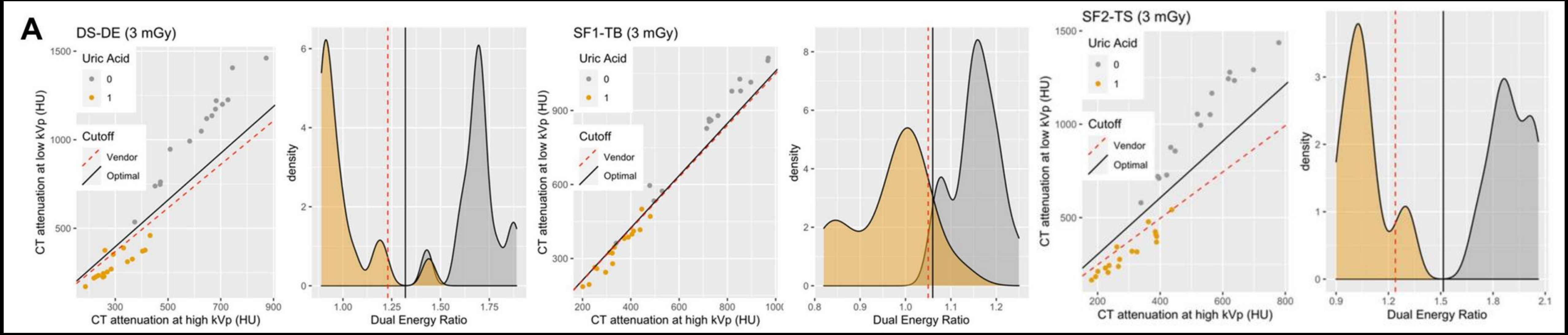


Kidney Stones

Low-dose dual-energy CT for stone characterization: a systematic comparison of two generations of split-filter single-source and dual-source dual-energy CT

Dominik Nakhostin[1] · Thomas Sartoretti[1] · Matthias Eberhard[1] · Bernhard Krauss[2] · Daniel Müller[3] · Hatem Alkadhi[1] · André Euler[1]

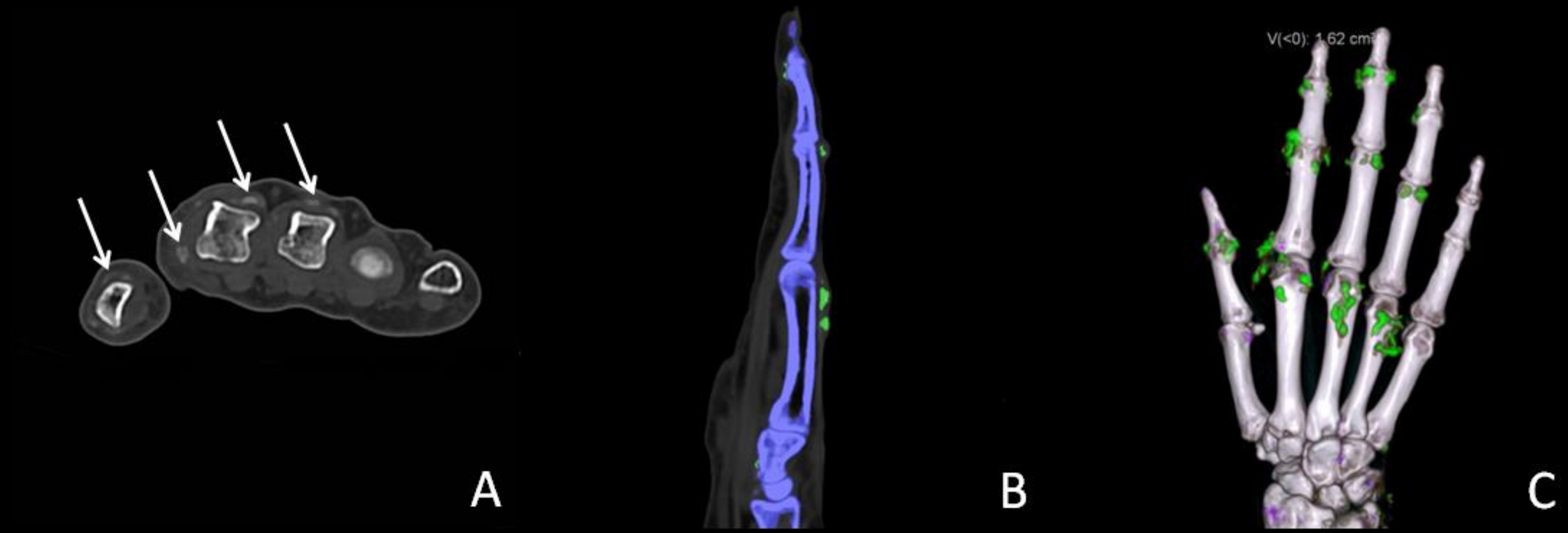
Nierensteine



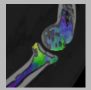
Low-dose dual-energy CT for stone characterization: a systematic comparison of two generations of split-filter single-source and dual-source dual-energy CT

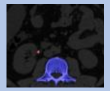
Dominik Nakhostin[1] · Thomas Sartoretti[1] · Matthias Eberhard[1] · Bernhard Krauss[2] · Daniel Müller[3] · Hatem Alkadhi[1] · André Euler[1]

DECT: Charakterisierung von Weichteilverkalkungen

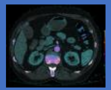


Dual-energy / Spektral-CT


Ca-Suppression


Harnsäure

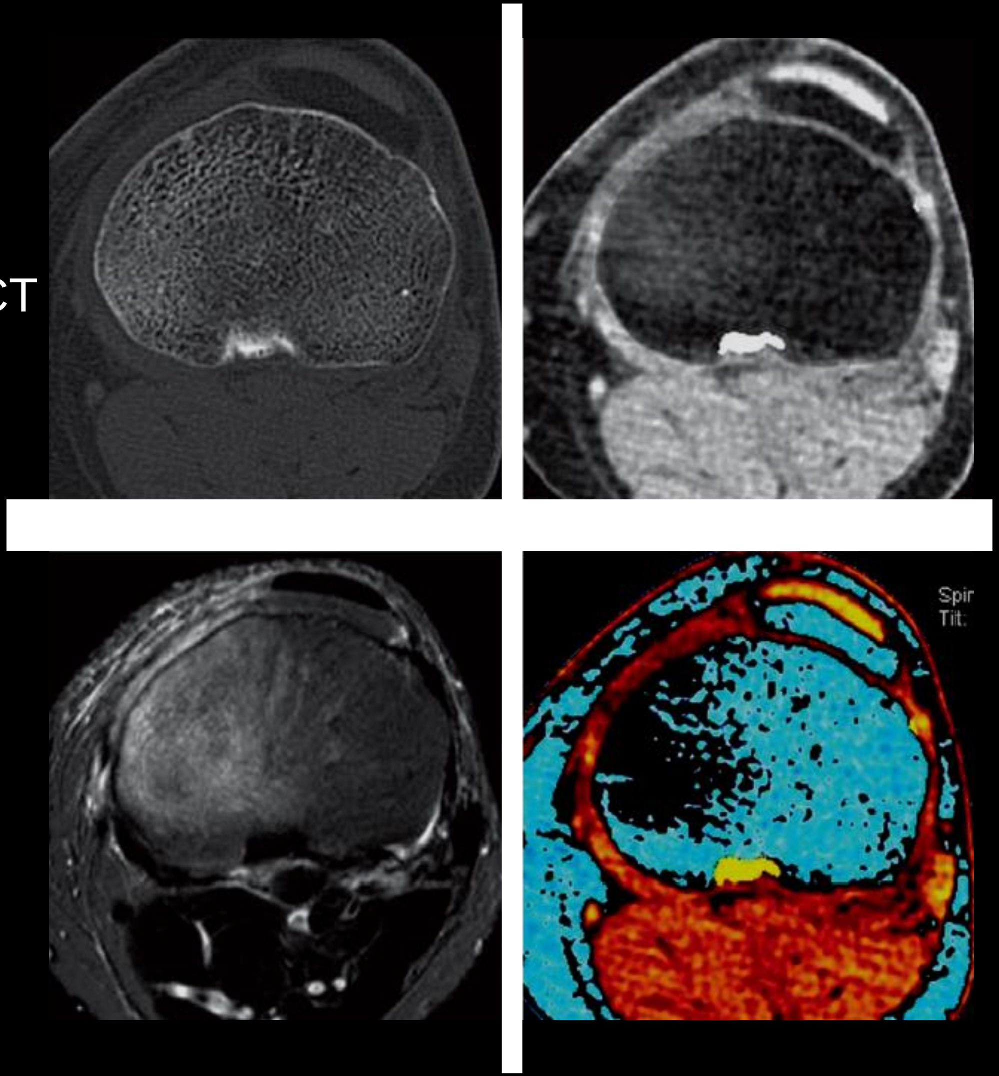

VNC


Iod


VMI


Konventionell

DECT: Calcium-Subtraktion



single-energy CT

dual-energy CT
non-calcium

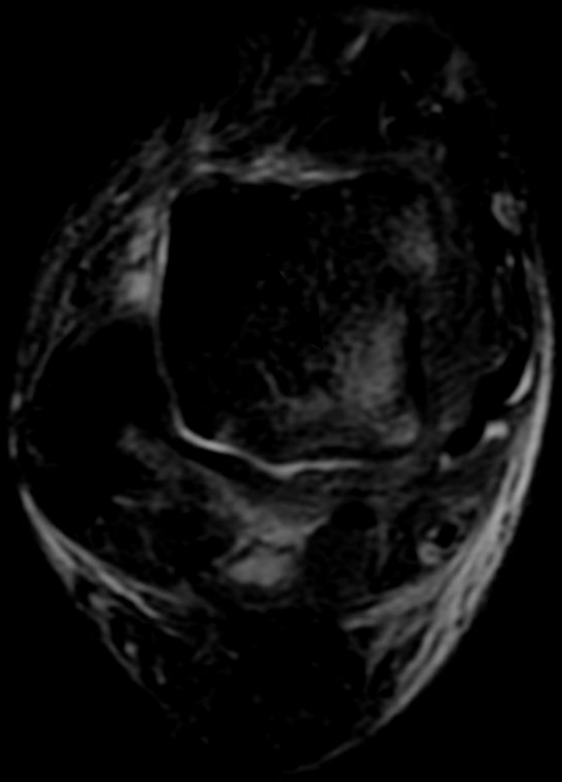
T2w MRT

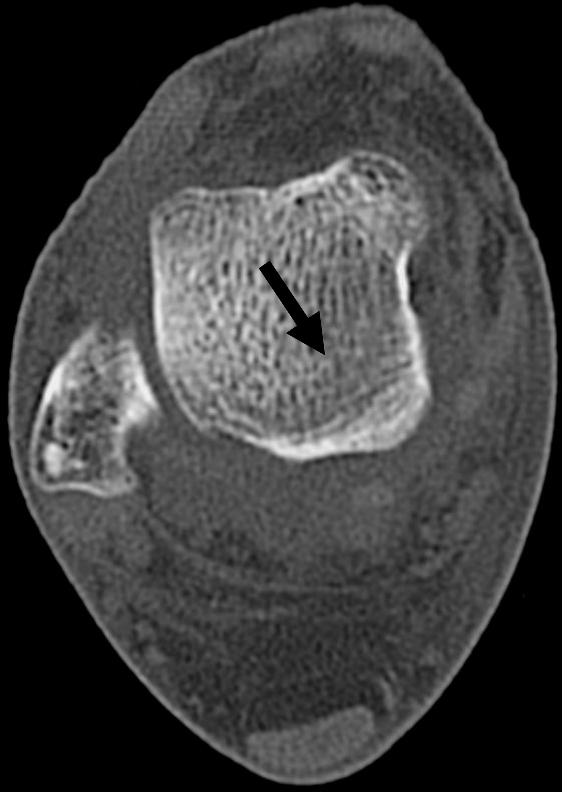
dual-energy CT
color-coded

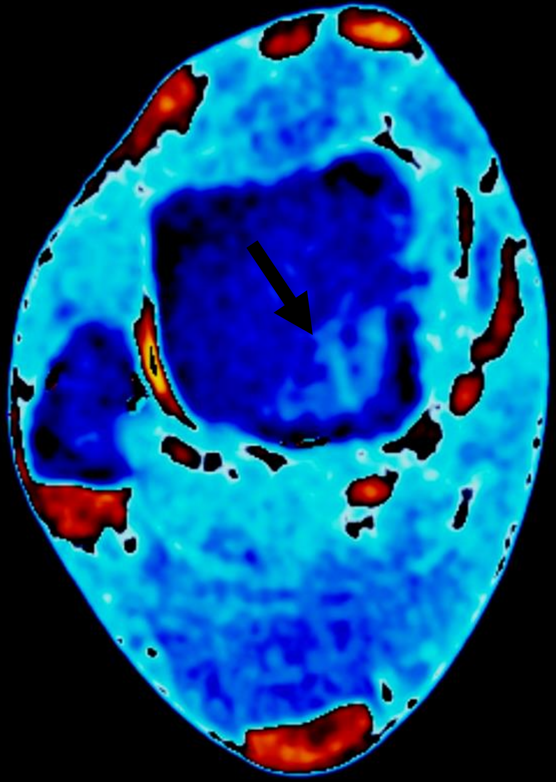
Pache G et al., *Radiology 2010;256:617-24*

DECT: Calcium-Subtraktion

T2w MR | single-energy CT | dual-energy CT

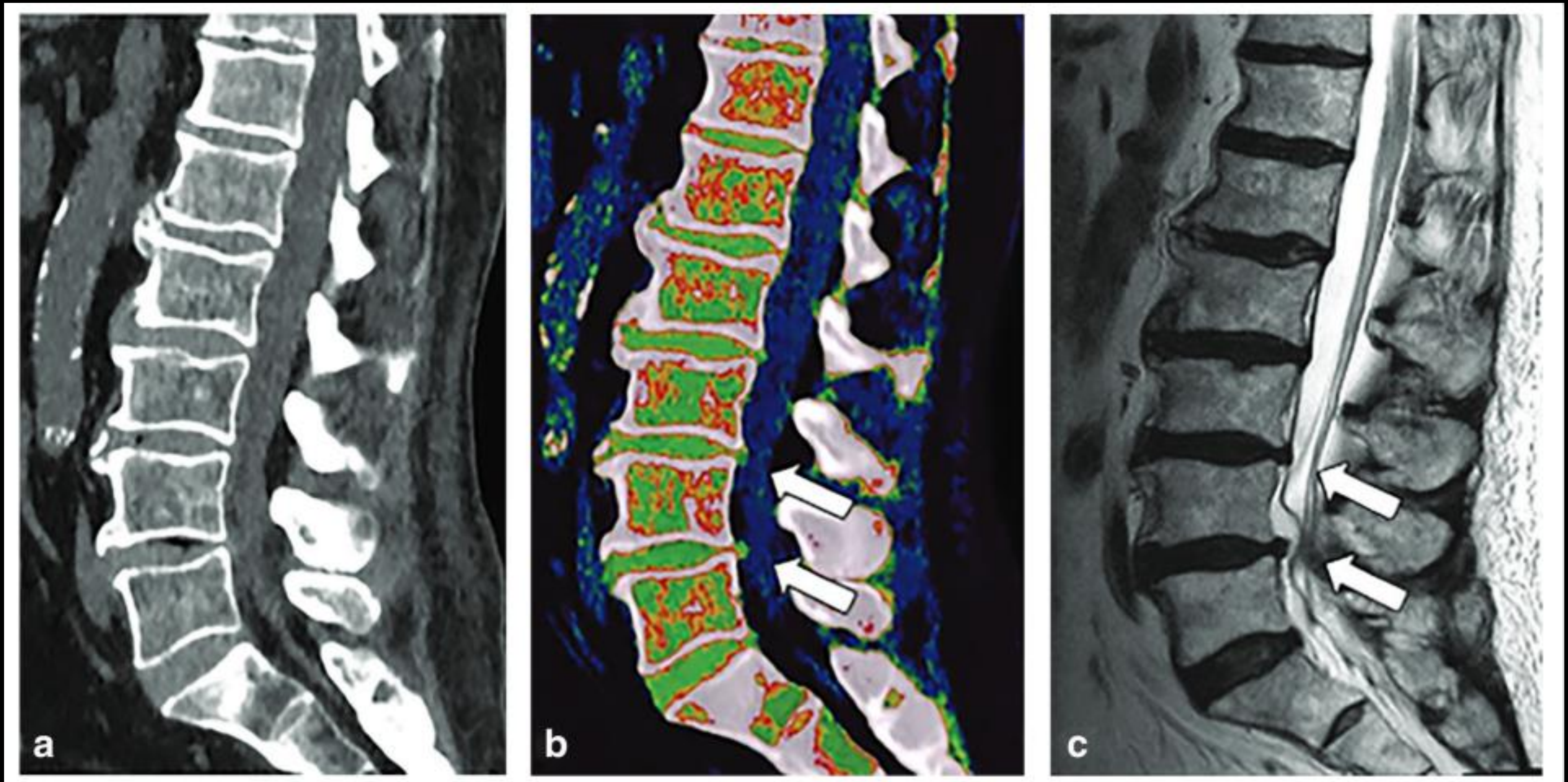






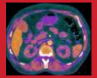
Guggenberger R et al., Radiology 2012;264:164-73

DECT: Calcium-Subtraktion



Booz C et al., Radiology 2019

Dual-energy / Spektral-CT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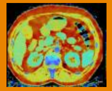
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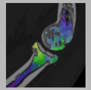
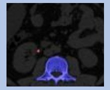
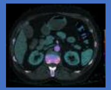

Ca-Suppression


Harnsäure


VNC


Iod


VMI


Konventionell

Zusammenfassung

- Es gibt mehrere unterschiedliche Techniken für die Dual-energy CT Bildgebung
- Dual-energy CT ermöglicht die Differenzierung und Charakterisierung einzelner Materialien
- Das Post-processing von Dual-energy CT-Daten kann in unterschiedlichen Bereichen einen Mehrwert bieten, z.B. zur Reduktion von KM oder zur Vermeidung zusätzlicher Scans oder Untersuchungen

Herzlichen Dank für Eure Aufmerksamkeit!

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Danke an Prof. Hatem Alkadhi für die Überlassung einiger Folien