PHILIPS

Radiation Oncology

Next generation synthetic CT for MR-only brain radiotherapy planning

Alex Dresner, PhD. Clinical adoption specialist
MR Oncology
AAPM 2021

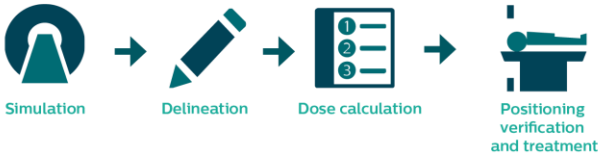
innovation you

MR-only radiotherapy planning

Experience the true potential and help drive the impact of MRI

MR + CT workflow

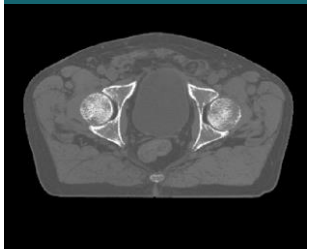
MR-only radiotherapy workflow



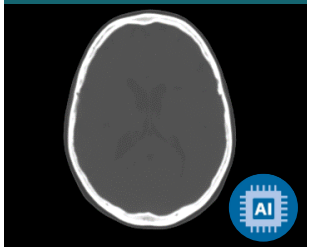
- Benefit from MRI's **superior soft-tissue contrast**
- **Eliminate tedious and error-prone** MR-CT registration
- Lower costs and make MR simulation **more affordable**
- Simplify workflows and **reduce patient burden**

MRCAT applications

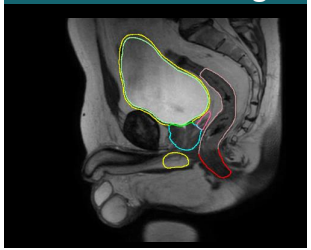
MRCAT Pelvis



MRCAT Brain



MRCAT Prostate + Auto-Contouring



Overview and definitions

PseudoCT = Synthetic CT = MRCAT, but not all versions are created equal

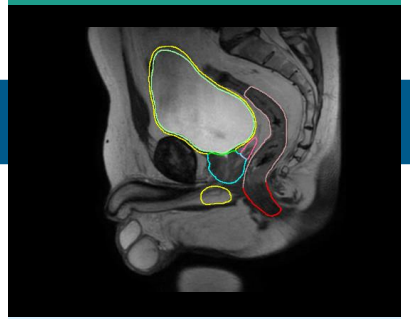
- Voxel-based mapping vs model-based mapping
- Bulk density assignments vs continuous Hounsfield Unit maps
- Edmund & Nyholm, Radiat. Oncol. 12, 28 (2017)
  Of 60 papers on pseudoCT for brain, only 10 had more than 20 patients*
- Accuracy criteria: dose equivalence for therapy planning
  Johnstone et al., Int J Radiat Oncol Biol Phys. 100(1), 199 (2018)

*Results from case studies are not predictive of results in other cases. Results in other cases may vary.

Philips MRCAT clinical applications

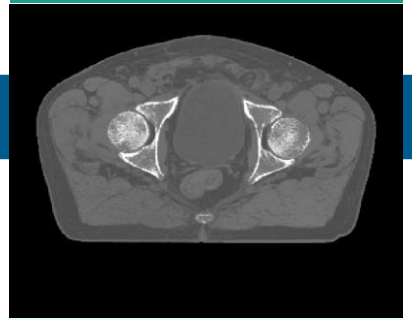
Continuous development

MRCAT Prostate + Auto-Contouring



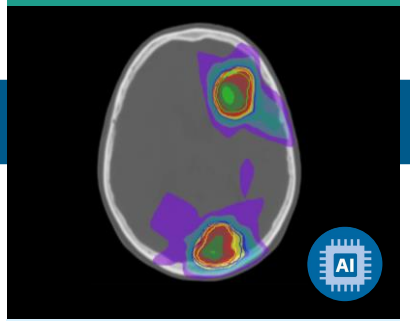
- ✓ Model-based segmentation
- ✓ Bulk density assignments of HU

MRCAT Pelvis



- ✓ Model-based segmentation
- ✓ Continuous Hounsfield Units (HU)

MRCAT Brain



- ✓ AI-based
- ✓ Continuous Hounsfield Units

✓ MRCAT-based dose plans equivalent[2] to CT-based plans

FDA, Health Canada and CE approved for clinical use in radiation therapy planning

Literature on Philips MRCAT & its performance

Philips whitepapers

▶ technical background of method

▶ aspects of dose comparison

… or the peer-reviewed publications:

1. **M. Maspero, P. R. Seevinck, G. Schubert, M. A. U. Hoesl, B. van Asselen, M. A. Viergever, J. J. W. Lagendijk, G. J. Meijer, C. A. T. van den Berg: "Quantification of confounding factors in MRI-based dose calculations as applied to prostate IMRT", Phys. Med. Biol. 62(3), 948-965 (2017)**

2. **N. Tyagi, S. Fontenla, J. Zhang, M. Cloutier, M. Kadbi, J. Mechalakos, M. Zelefsky, J. Deasy and M. Hunt: "Dosimetric and workflow evaluation of first commercial synthetic CT software for clinical use in pelvis", Phys. Med. Biol. 62(8), 2961-2975 (2017)**

3. **R. L. Christiansen, H. R. Jensen, C. Brink: "Magnetic resonance only workflow and validation of dose calculation for radiotherapy of prostate cancer", Acta Oncol. 56(6), 787-791 (2017)**

4. **R. Kemppainen, S. Suilamo, T. Tuokkola, P. Lindholm, M. H. Deppe, J. Keyrilainen: "Magnetic resonance-only simulation and dose calculation in external beam radiation therapy: a feasibility study for pelvic cancers", Acta Oncol. 56(6), 792-798 (2017)**

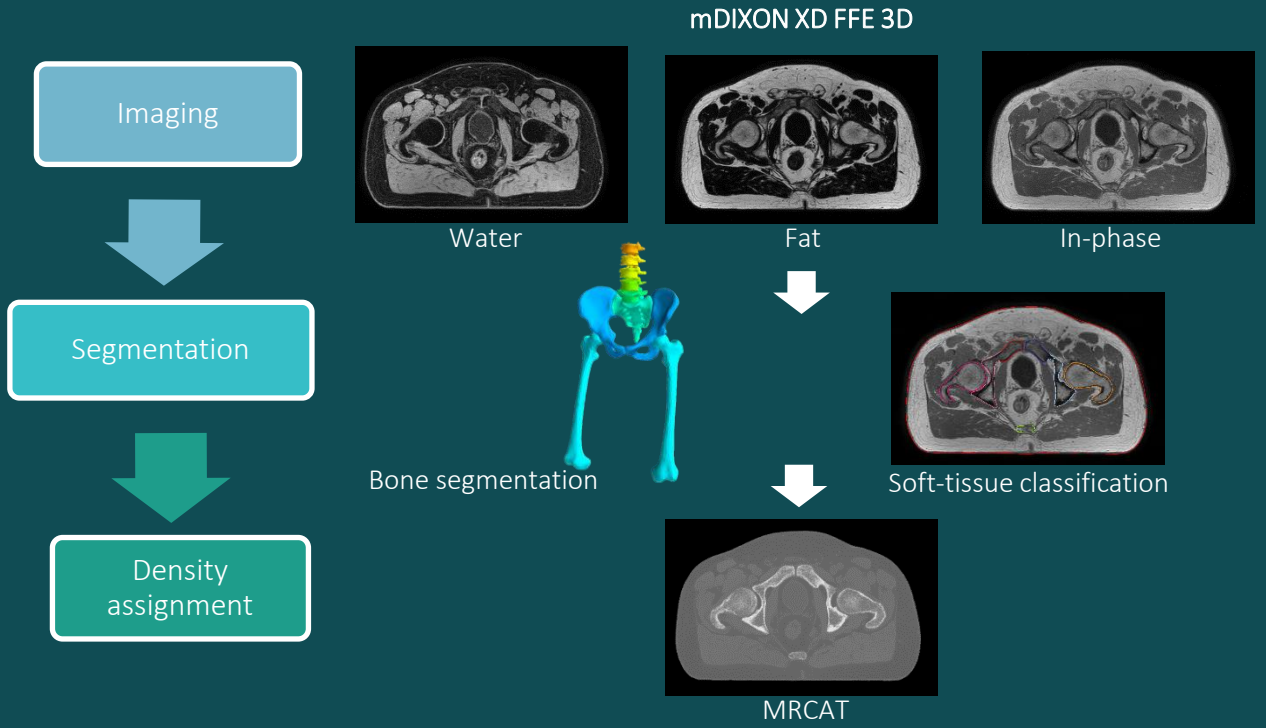
5. **N. Tyagi, S. Fontenla, M. Zelefsky, M. Chong-Ton, K. Ostergren, N. Shah, L. Warner, M. Kadbi, J. Mechalakos, M. Hunt: "Clinical workflow for MR-only simulation and planning in prostate", Radiat. Oncol. 12(1), 119 (2017)**

6. **M. Maspero, C. A. T. van den Berg, G. Landry, C. Belka, K. Parodi, P. R. Seevinck, B. W. Raaymakers and C. Kurz: "Feasibility of MR-only proton dose calculations for prostate cancer radiotherapy using a commercial pseudo-CT generation method", Phys. Med. Biol. 62(24), 9159 (2017)**

7. **R. Kemppainen, T. Vaara, T. Joensuu, and T. Kiljunen: "Accuracy and precision of patient positioning for pelvic MR-only radiation therapy using digitally reconstructed radiographs", Phys. Med. Biol. 63(5), 055009 (2018)**

Automatic generation of synthetic CT images

MRCAT - Assignment of continuous Hounsfield units



- Model-based segmentation of bones and body outline
- Assignment of **continuous Hounsfield Units** based on fat-water content and bone segmentation
- Runs parallel to image acquisition – adding no time to the scanning session

Courtesy: Turku University Hospital, Turku, Finland

Intensity-based classification using mDixon

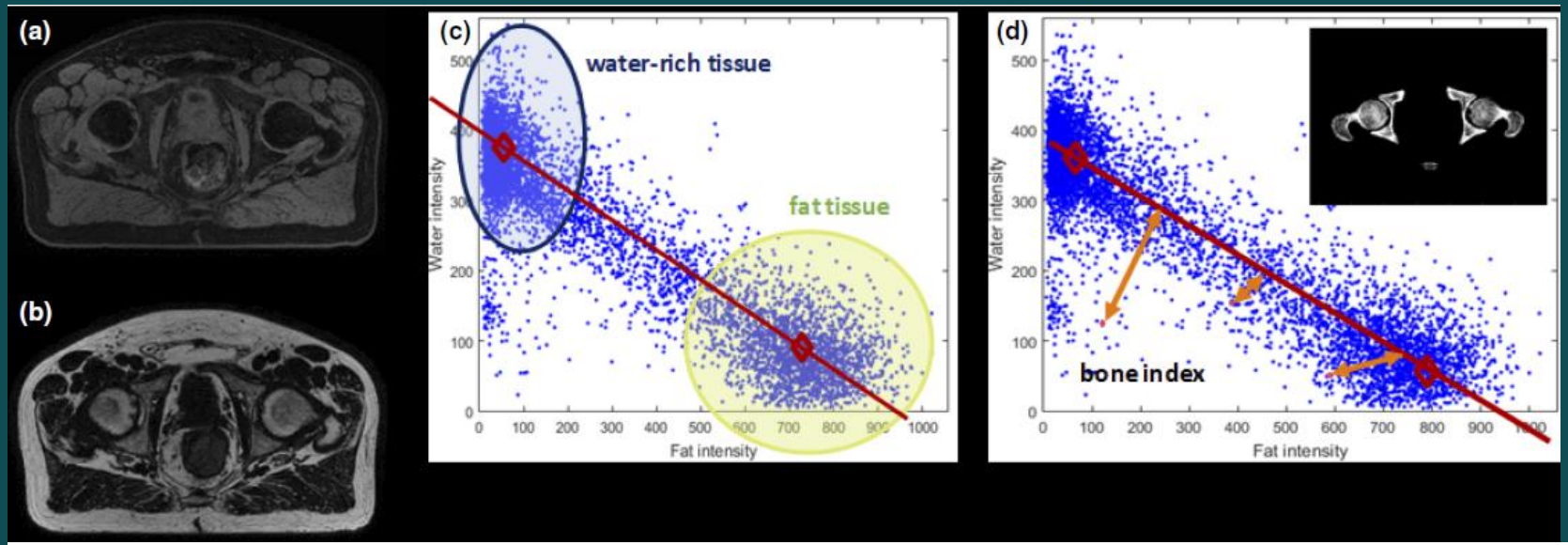
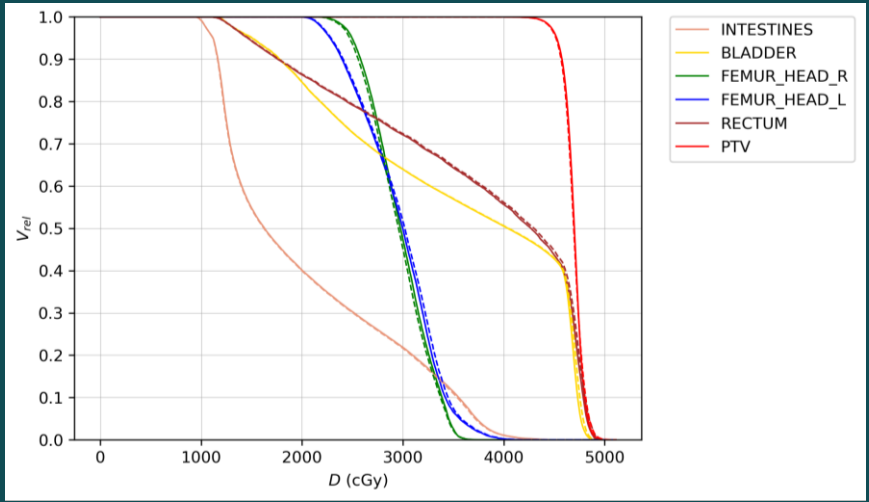


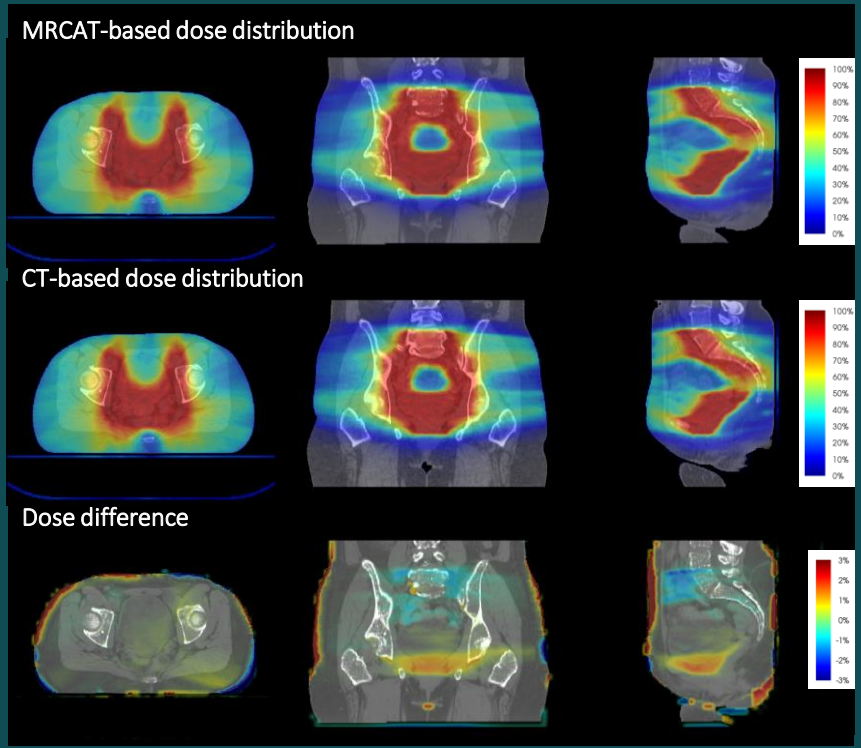
Fig. 1. Intensity-based classification using mDixon MRI to generate sCT. (a) water source image (b) fat source image. (c) Water intensity vs. fat intensity scatter plot illustrating the estimated centers of water-rich and fat-rich voxels for linear and continuous soft tissue voxel mapping. (d) Illustration of bone HU classification based on distance from water-fat classification line (MRI: magnetic resonance imaging; sCT: synthetic computed tomography, HU: Hounsfield unit).

Accuracy in dose planning

CT-equivalent[1] dose plans

Validation studies have shown that the simulated dose based on MRCAT images does not differ ([1]Gamma analysis criterion 3%/3mm realized in 99% of voxels within the PTV or exceeding 75% of the maximum dose) in 95% of the pelvic cancer patients when compared with CT-based plan for EBRT





Ingenia MR-RT 1.5T. Courtesy: Turku University Hospital, Turku, Finland. CT(____) and MRCAT (------)

Some results on MRCAT

Dosimetric and workflow evaluation of first commercial synthetic CT software for clinical use in pelvis

Neelam Tyagi Ph.D.[1], Sandra Fontenla M.S.[1], Jing Zhang M.S.[1], Michelle Cloutier B.S.[1], Mo Kadbi Ph.D.[2], Jim Mechalakos Ph.D.[1], Michael Zelefsky MD[1], Joe Deasy Ph.D.[1] and Margie Hunt M.S.[1]

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[2]Philips Healthcare, 595 Miltner Road, Cleveland, OH 44143

[3]Department of Radiation Oncology, Memorial Sloan Kettering Cancer Center, 1275 York Avenue, NY, NY 10065

Quantification of confounding factors in MRI-based dose calculations as applied to prostate IMRT

Matteo Maspero[1], Peter R. Seevinck[1], Gerald Schubert[2], Michaela A.U. Hoesl[1], Bram van Asselen[1], Max A. Viergever[1], Jan J.W. Lagendijk[1], Gert J. Meijer[1] and Cornelis A.T. van den Berg[1]

[1] Universitair Medisch Centrum Utrecht, Center for Image Sciences, Heidelberglaan 100, 3584 CX, Utrecht, The Netherlands

[2] Philips Healthcare, MR-Therapy, Ayritie 4, PL 185, 01511 Vantaa, Finland

ACTA ONCOLOGICA, 2017
http://dx.doi.org/10.1080/0284186X.2017.1290275

ORIGINAL ARTICLE

Magnetic resonance only workflow and validation of dose calculations for radiotherapy of prostate cancer

Rasmus L. Christiansen[a], Henrik R. Jensen[a] and Carsten Brink[a,b]

[a]Laboratory of Radiation Physics, Department of Oncology, Odense University Hospital, Odense, Denmark; [b]Institute of Clinical Science, University of Southern Denmark, Odense, Denmark

pCTs compared		Calibration		Confounding	RelDiff±1 SD [%]	
Ref	Test	Ref	Test	Factors	CTV	V_{Body}
		Clini	*MRcal*		1.0 ± 0.6	0.14 ± 0.07
CT_{reg}	MR_{pCT}	*MRcal*	*MRcal*	All factors	0.33 ± 0.39	0.04 ± 0.06
CT_{reg}	CT_{reg}	*Clini*	*MRcal*	ED conversion	0.7 ± 0.2	0.10 ± 0.03
CT_{reg}	CT_{strat}	*Clini*	*Clini*	Pseudo-CT generation	0.16 ± 0.13	-0.03 ± 0.02
CT_{water}	MR_{water}	*Clini*	*Clini*	Inter-scan differences	0.01 ± 0.35	0.00 ± 0.06

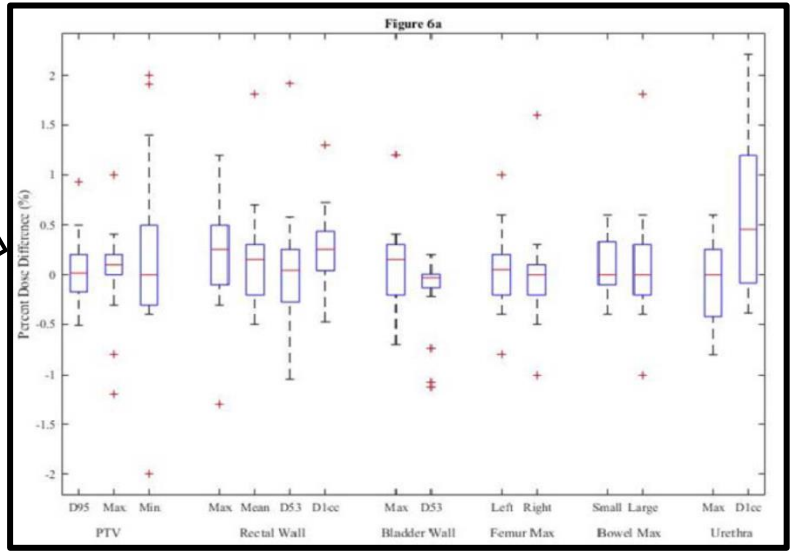

Table 1. Median gamma pass rates shown for selected structures for CT vs pseudo CT and CT vs uniform density dose calculations. 16.7–83.3 percentiles mimicking 1 standard deviation, had data been normally distributed are shown in brackets.

	2% and 2 mm		1% and 1 mm	
	Pseudo CT	Uniform density	Pseudo CT	Uniform density
PTV78	100 (99.7–100)	100 (98.4–100)	99.9 (96.7–100)	97.1 (56.5–100)
Prostate	100 (100–100)	100 (99.9–100)	100 (98.7–100)	98.5 (23.7–100)
Seminal vesicles	100 (100–100)	100 (100–100)	100 (99.3–100)	100 (71.1–100)
Rectum	100 (99.1–100)	100 (98.2–100)	100 (94.9–100)	100 (89.9–100)
Small bowel incl. sigmoid	100 (99.6–100)	100 (99.9–100)	100 (97.5–100)	100 (97.6–100)
Bladder	100 (100–100)	100 (100–100)	100 (99.9 –100)	100 (95.8–100)
Penile bulb	100 (100–100)	100 (100–100)	100 (100–100)	100 (100–100)
Femoral heads	100 (100–100)	100 (100–100)	100 (100–100)	100 (99.1–100)
Body	99.7 (99.3–99.8)	99.7 (99.4–99.9)	98.9 (98.3–99.2)	98.9 (98.2–99.3)

Table 2. Mean gamma pass rates (and their standard deviation) shown for selected structures for CT vs pseudo CT and CT vs uniform density dose calculations for comparison with results of other groups, although data are not normally distributed.

	2% and 2 mm		1% and 1 mm	
	Pseudo CT	Uniform density	Pseudo CT	Uniform density
PTV78	99.8 (0.5)	98.9 (2.7)	97.3 (7.1)	82.5 (24.3)
Prostate	99.9 (0.3)	97.6 (7.7)	97.4 (10.4)	74.3 (35.5)
Seminal vesicles	99.9 (0.3)	99.8 (0.7)	96.7 (10.0)	88.7 (19.3)
Rectum	99.2 (2.7)	98.7 (3.2)	96.8 (7.0)	95.4 (8.6)
Small bowel incl. sigmoid	99.7 (1.0)	98.2 (8.8)	98.9 (2.3)	95.9 (17.8)
Bladder	100.0 (0.0)	100.0 (1.8)	98.9 (4.8)	96.2 (9.9)
Penile bulb	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)	99.0 (5.5)
Femoral heads	100.0 (0.0)	99.9 (0.6)	100.0 (0.2)	97.6 (10.2)
Body	99.5 (0.4)	99.5 (0.7)	98.7 (0.9)	98.1 (3.0)

Literature validation of MRCAT Pelvis

Methods for commissioning outlined in Turku University Hospital study

		Prostate cancer			Rectal cancer	Gynecological cancer
		Pelvic lymph nodes (n=15)	Post-operative (n=15)	Definitive (n=15)	(n=15)	(n=15)
Mean pass rate for a 2%/ 2 mm gamma criterion (%)		98	98	99	96	97
Mean relative dose difference between MRCAT and CT (%)	PTV	0.0	0.1	0.1	0.1	-0.2
	OARs	Less than 0.2%				
		Less than -0.3%				

Kemppainen R, et al. Assessment of dosimetric and positioning accuracy of a magnetic resonance imaging-only solution for external beam radiotherapy of pelvic anatomy. Phys Imag Radiat Oncol 11, 1-8 (2019).

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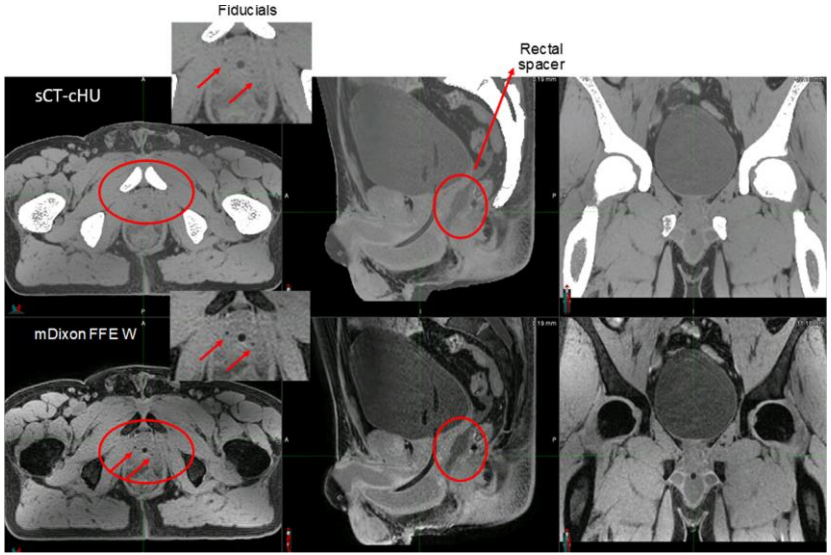
DOI: 10.1002/acm2.13205

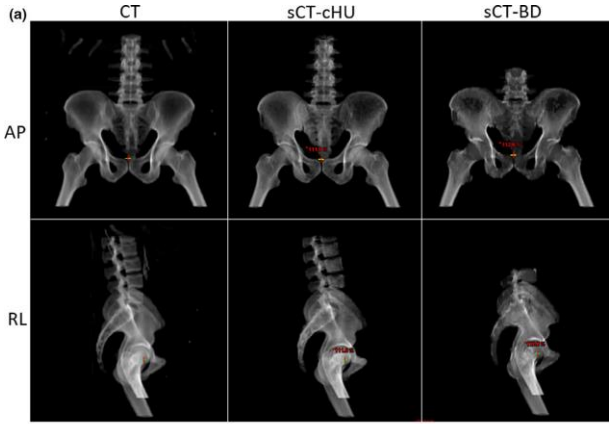
RADIATION ONCOLOGY PHYSICS

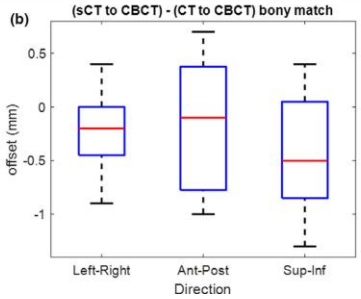
WILEY

A multi-institutional analysis of a general pelvis continuous Hounsfield unit synthetic CT software for radiotherapy

Victoria Y. Yu[1] | Jani Keyrilainen[2] | Sami Suilamo[2] | Ilyes Beslimane[1] | Alex Dresner[3] | Aleksi Halkola[3] | Uulke A. Van der Heide[4] | Neelam Tyagi[1]







Yu, V.Y., Keyrilainen, J., Suilamo, S., Beslimane, I., Dresner, A., Halkola, A., Van der Heide, U.A. and Tyagi, N. (2021), A multi-institutional analysis of a general pelvis continuous Hounsfield unit synthetic CT software for radiotherapy. J Appl Clin Med Phys, 22: 207-215. https://doi.org/10.1002/acm2.13205

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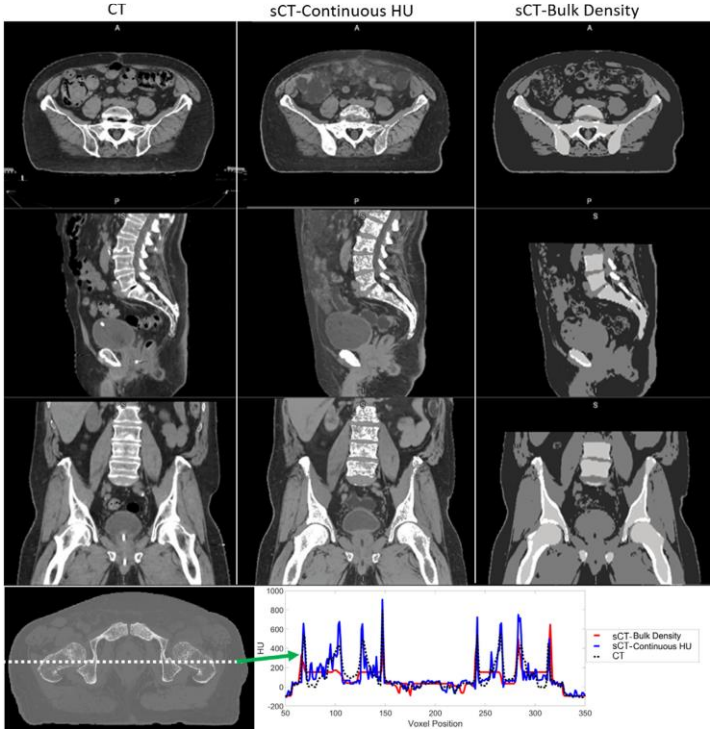
5 | CONCLUSIONS

MRCAT general pelvis with continuous HU generated realistic sCTs and DRRs to enable MRI-only planning for general pelvis anatomy. Two-stack acquisition enabled geometrically accurate MRI as well as sCT images and allowed anatomic coverage up to L1–L3 vertebrae



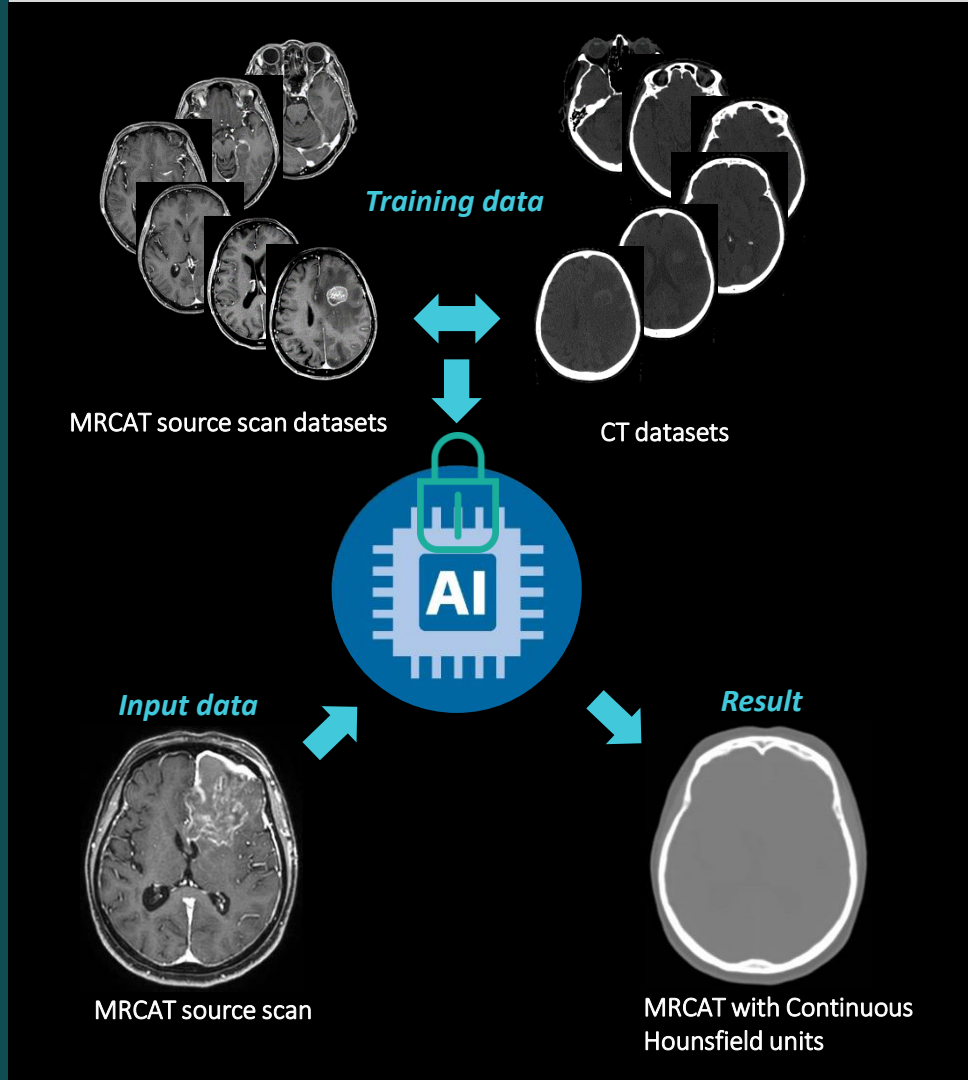
MRCAT Brain: Powered by AI

Training

MRCAT Brain algorithm is trained on matched pairs of clinical CT with 1.5T and 3.0T MR datasets from various institutions

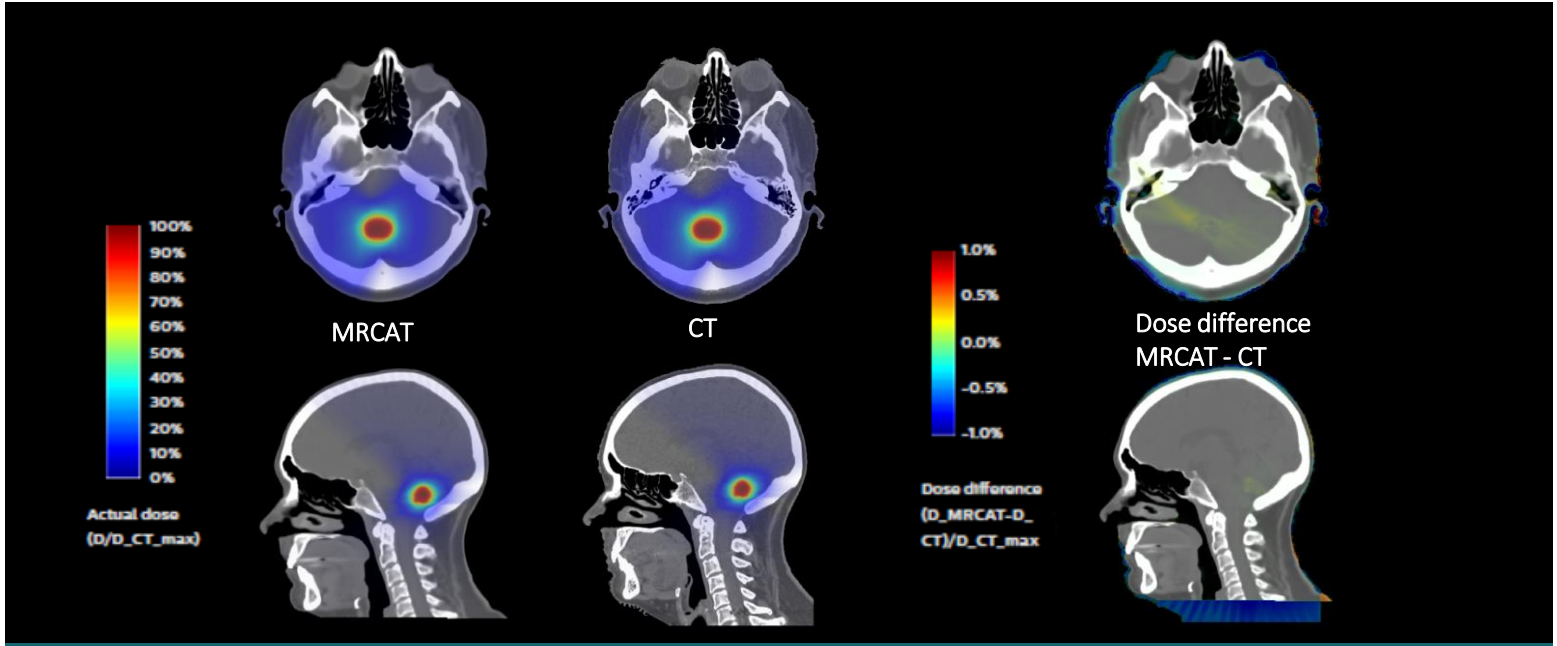
MRCAT Brain reconstruction

- Fast computation of attenuation maps directly on the MR console
- Continuous Hounsfield units for CT-like image appearance



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

MRCAT-based dose plans are robust and as accurate as CT-based plans

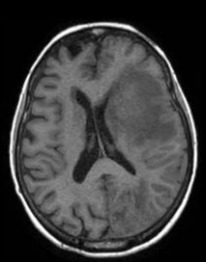


The mean dose in the PTV does not differ more than 1% in MRCAT-based plans as compared to CT-based plans for 95% of the patient cases

Training requirement: clinical datasets must represent real-world usage

Contrast agents

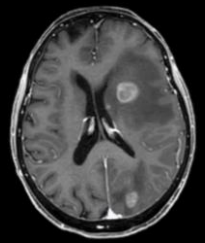
Without contrast



in-phase

MRCAT

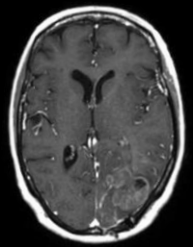
With contrast



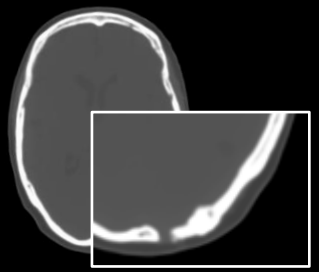
in-phase

MRCAT

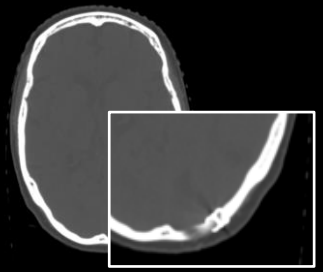
Surgical clips



T1W mDIXON in-phase – Post contrast



MRCAT



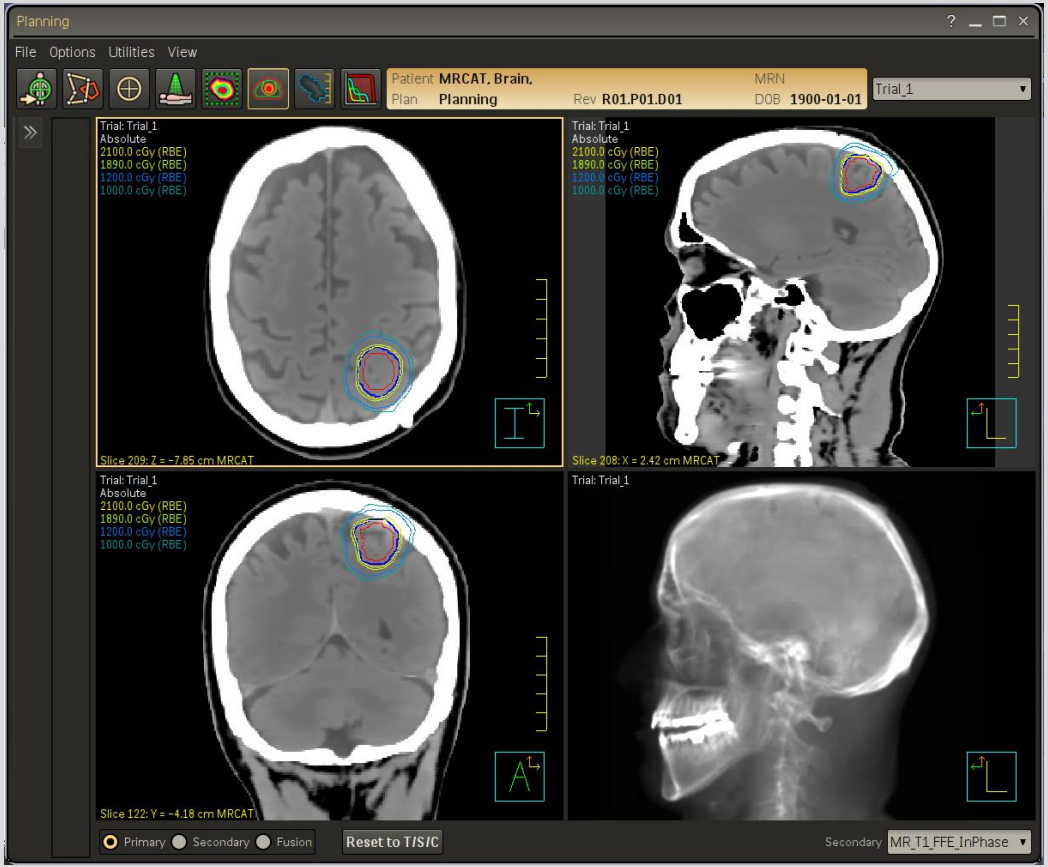
CT

Courtesy: Turku University Hospital, Finland. Ingenia MR-RT 1.5T.

Goal: MRCAT as primary imaging modality

MRCAT images conform to the DICOM CT standard

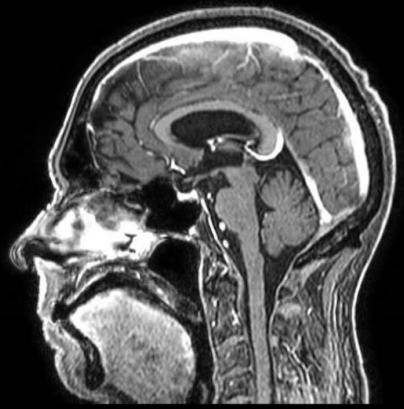
- For automatic export to treatment planning systems
- Import as primary image dataset for dose calculations and DRR generation



Pinnacle radiation therapy planning software sold separately from MRCAT

Accurate MR-based patient positioning

- High-resolution MRCAT data can be used for patient positioning at the linac
- Validation studies have shown that MRCAT-based DRRs are within **1 mm accuracy** compared to CT-based DRRs for 95% of cases



MultiPlanar Reconstruction (MPR) of in-phase MRCAT source scan

Digitally Reconstructed radiogram (DRR)

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

Example of Prostate MRCAT Commissioning from Turku University Hospital

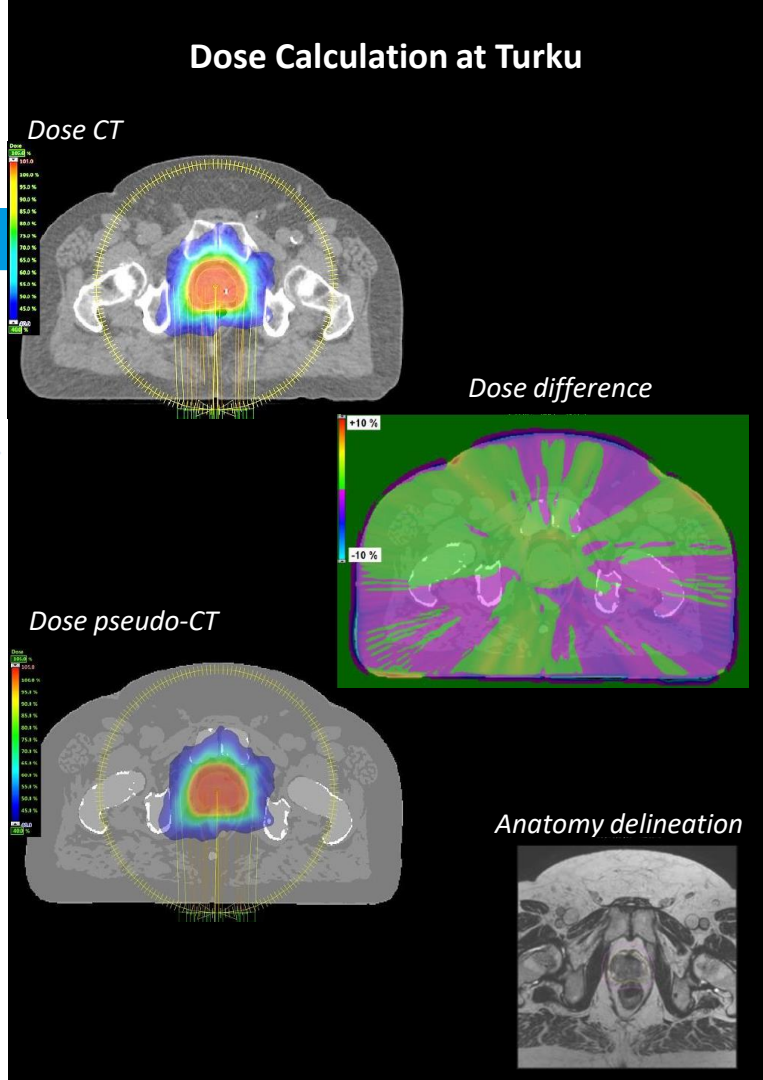
VARSINAIS-SUOMEN SAIRAANHOITOPIIRI
HOSPITAL DISTRICT OF SOUTHWEST FINLAND

MRI-only Planning for Prostate Cancer
- Three-phase Validation Process -

Phase 1 Jan – Sep 2016	Phase 2 Oct 2016 – Feb 2017	Phase 3 Mar 2017 – Mar 2018
· CT and MRI acquisition	· CT and MRI acquisition	· MRI acquisition
· Image registration	· Image registration	· Delineation on MRI
· Delineation on MRI	· Delineation on MRI	· Planning on MRI
· Planning on CT and MRI	· Planning on MRI and CT	· RT based on MRI plan
· Testing & preliminary dose calculation comparisons	· Dosimetric agreement with CT-based plan	
· RT based on CT plan	· RT based on MRI plan	
• 74 prostate cancer patients • 8 months	• 62 prostate cancer patients • 5 months • Average difference in PTV_{mean} dose was 0.8%	• 164 prostate cancer patients • 13 months

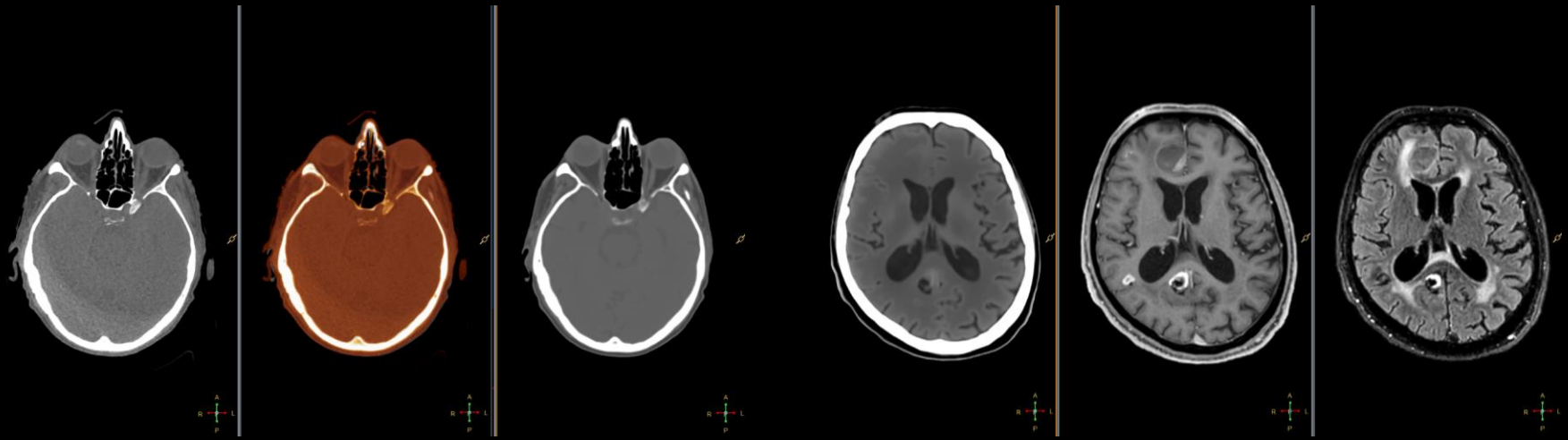
ESTRO Satellite Symposium – Apr 23, 2018 Jani Keyriläinen PhD - Tyks Turku Finland

Dr. Jani Keyriläinen ESTRO Satellite Symposium 2018



MRCAT Brain in clinical use

Examples with pathology

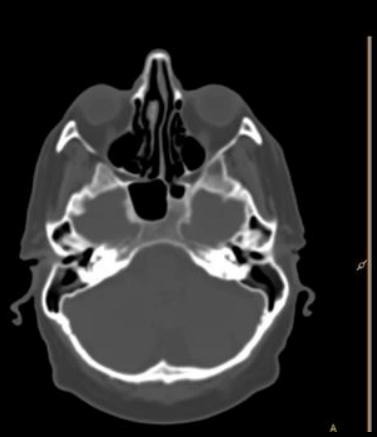


CBCT | Fusion | MRCAT (bone window) | MRCAT | MRCAT source mDIXON | FLAIR

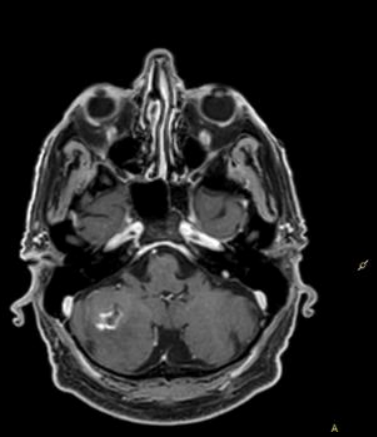
Hôpital de La Tour

Courtesy: Hôpital de la Tour, Switzerland. Ingenia MR-RT 1.5T

MRCAT Brain in clinical use

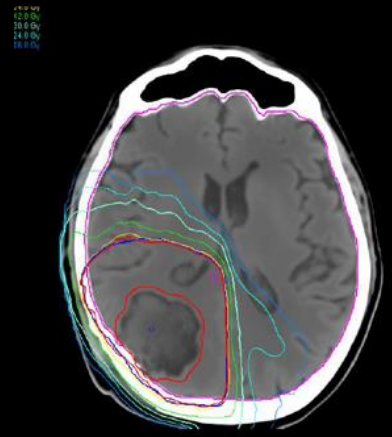


MRCAT Brain

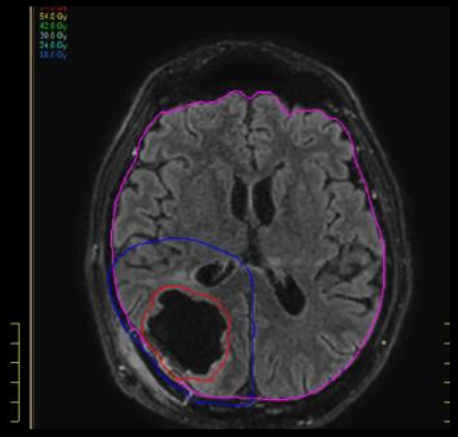


MRCAT source 3D T1W FFE + contrast

Metastasis



MRCAT Brain



FLAIR

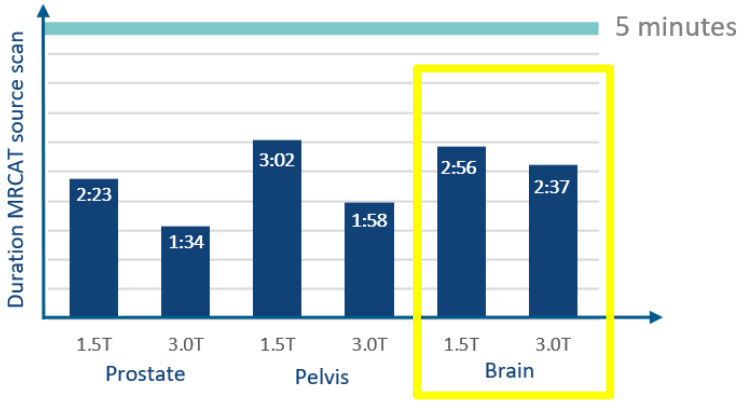
Glioblastoma

Courtesy: Grégory Bolard, Hôpital de la Tour, Switzerland
Ingenia MR-RT 1.5T

Next generation synthetic CT:

MRCAT Brain is the start of the next generation of synthetic CT

- Based on a single scan under 3 minutes
- Computed on the scanner console
- Continuous Hounsfield Units
- Computed with artificial intelligence
- FDA approved for use in radiation therapy planning
  - Tested for dosimetric accuracy
  - Local commissioning of MRCAT Brain to replace CT can follow published guidelines

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