Medical Imaging Basics

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My background

Adjunct Professor, University of Turku (2021)
Physics and Technology of Magnetic Resonance Imaging

Qualified Medical Physicist (2010)

Ph.D. in Physics, Univeristy of Oulu (2009)
Atomic and molecular physics

Ph.Lic. in Physics, Univeristy of Oulu (2007)

M.Sc. in Physics, Univeristy of Oulu (2002)

Physicist
Terveystalo · Full-time
Apr 2021 - Present · 1 yr 2 mos

Medical physicist with special focus in supporting and developing MRI.

Medical Physicist
iRad Oy · Part-time
Sep 2009 - Present · 12 yrs 9 mos

Turku University Hospital
14 yrs 4 mos

Assistant Chief Physicist
Mar 2019 - Apr 2021 · 2 yrs 2 mos

Department of Radiology

Medical physicist
Jan 2011 - Feb 2019 · 8 yrs 2 mos

MRI physicist at the Medical Imaging Centre of the Southwest Finland

Specializing Physicist
Jan 2007 - Dec 2010 · 4 yrs

Researcher / PhD Student
University of Oulu
Jun 2000 - Dec 2006 · 6 yrs 7 mos

History of Medical Imaging

Medical imaging began in November 1895 with Wilhelm Conrad Röntgen’s discovery of X-ray.

1920 – Fluoroscopy
1940 – X-ray tomography

Angiography
Mammography

Nuclear Medicine, PET

1970 Ultrasound, Computed Tomography, Magnetic Resonance Imaging

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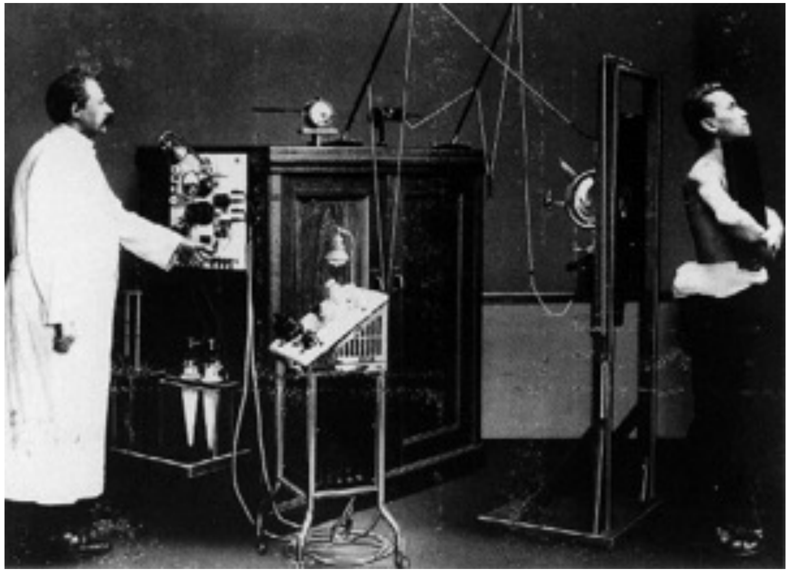
Radiography

Medical imaging began in November 1895 with Wilhelm Conrad Röntgen's discovery of X-ray.

For the first fifty years of radiology, the primary examination involved creating an image by focusing x-rays through the body part of interest and directly onto a single piece of film inside a special cassette. **In the earliest days, a head x-ray could require up to 11 minutes of exposure time**.

Now, modern x-rays images are made in milliseconds and the x-ray dose currently used is as little as 2% of what was used for that 11 minute head exam 100 years ago. Further, modern x-ray techniques have significantly more spatial resolution and contrast detail. This improved image quality allows the diagnosis of smaller pathology that could not be detected with older technology.



An x-ray system from the pioneering days.
Patients still had to hold the cassettes themselves

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Fluorescent screens

The next development involved the use fluorescent screens and special glasses so the doctor could see x-ray images in real time. This caused the doctor to stare directly into the x-ray beam, creating unwanted exposure to radiation. In 1946, George Schoenander developed the film cassette changer which allowed a series of cassettes to be exposed at a movie frame rate of 1.5 cassettes per second. By 1953, this technique had been improved to allow frame rates up to 6 frames per second by using a special "cut film changer."

A major development along the way was the application of pharmaceutical contrast medium to help visualize organs and blood vessels with more clarity and image contrast. These contrast media agents (liquids also referred to as "dye") were fir st administered orally or via vascular injection between 1906 and 1912 and allowed doctors to see the blood vessels, digestive and gastro-intestinal systems, bile ducts and gall bladder for the first time.

In 1955, the x-ray image intensifier (also called I.I.) was developed and allowed the pick up and display of the x-ray movie using a TV (television) camera and monitor. By the 1960's, the fluorescent system (which had become quite complex with mirror optic systems to minimize patient and radiologist dose) was largely replaced by the image intensifier/TV combination. Together with the cut-film changer, the image Intensifier opened the way for a new radiologic sub-specialty know as angiography to bloss om and allowed the routine imaging of blood vessels and the heart.

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Digital Imaging Techniques

Digital imaging techniques were implemented in the 1970's with the first clinical use and acceptance of the Computed Tomography or CT scanner, invented by Godfrey Hounsfield. Analog to digital converters and computers were also adapted to conventional fluoroscopic image intensifier/TV systems in the 70's as well. Angiographic procedures for looking at the blood vessels in the brain, kidneys, arms and legs, and the blood vessels of the heart all have benefited tremendously from the adaptation of digital technology.

Over the next ten to fifteen years a large majority of conventional x-ray systems will also be upgraded to all digital technology. Eventually, all of the film cassette/film screen systems will be replaced by digital x-ray detectors.

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Benefits of Digital Technology to all X-Ray systems

- less x-ray dose can often be used to achieve the same high quality picture as with film

- digital x-ray images can be enhanced and manipulated with computers

- digital images can be sent via network to other workstations and computer monitors so that many people can share the information and assist in the diagnosis

- digital images can be archived onto compact optical disk or digital tape drives saving tremendously on storage space and manpower needed for a traditional x-ray film library

- digital images can be retrieved from an archive at any point in the future for reference.

Some modalities like mammography require extremely high resolution film to show the small breast cancers. Digital detectors capable of a similarly high resolution are under development and will hopefully be available in the future. However, digital imaging is already being used in parallel to high resolution film in breast imaging and breast biopsy systems.

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Computed Tomography

CT imaging (also called CAT scanning for Computed Axial Tomography) was invented in 1972 by Godfrey Hounsfield in England. Hounsfield used gamma rays (and later x-rays) and a detector mounted on a special rotating frame together with a digital compute r to create detailed cross sectional images of objects. Hounsfield's original CT scan took hours to acquire a single slice of image data and more than 24 hours to reconstruct this data into a single image. Today's state-of-the-art CT systems can acquire a single image in less than a second and reconstruct the image instantly.

The invention of CT was made possible by the digital computer. The basic algorithms involved in CT image reconstruction are based on theories proposed by the scientist Radon in the late 1700's. To honor his remarkable discovery, Hounsfield was awarded the Nobel Prize and was granted Knighthood by the Royal Family of England.

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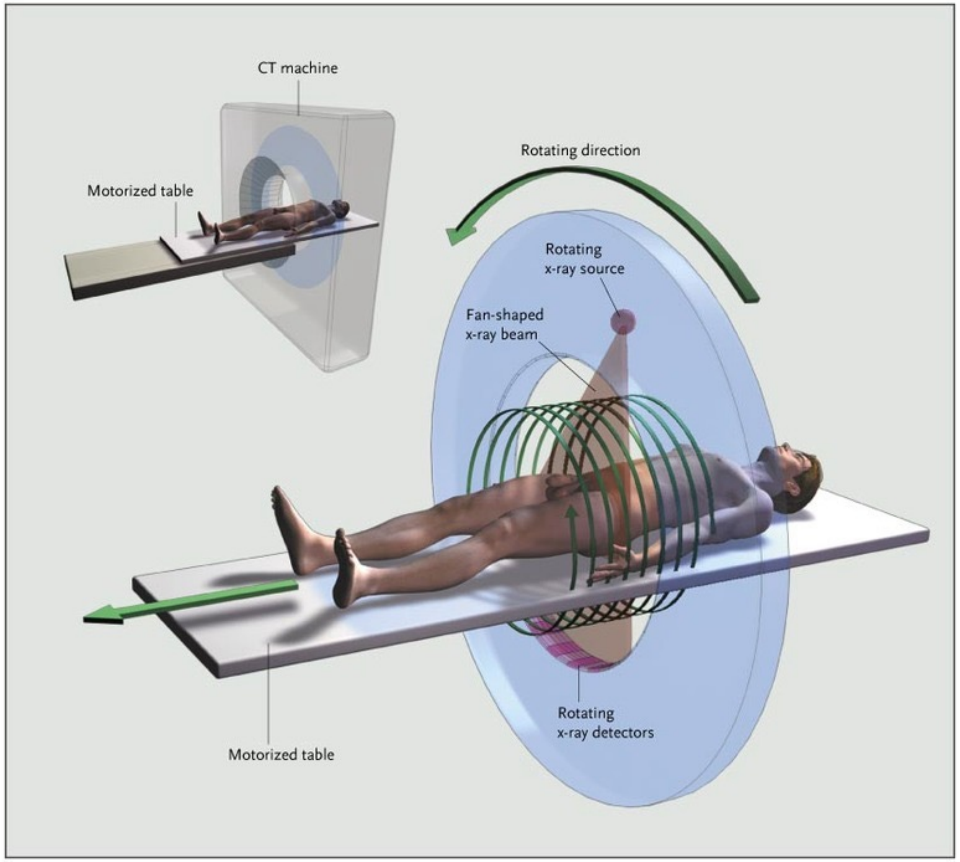
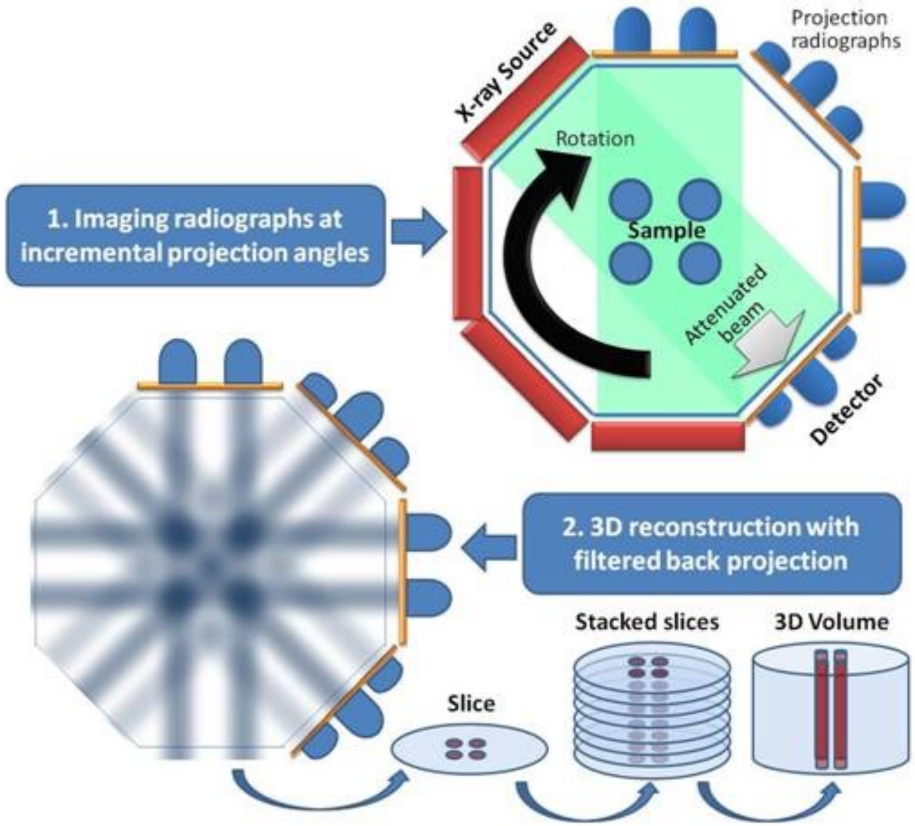
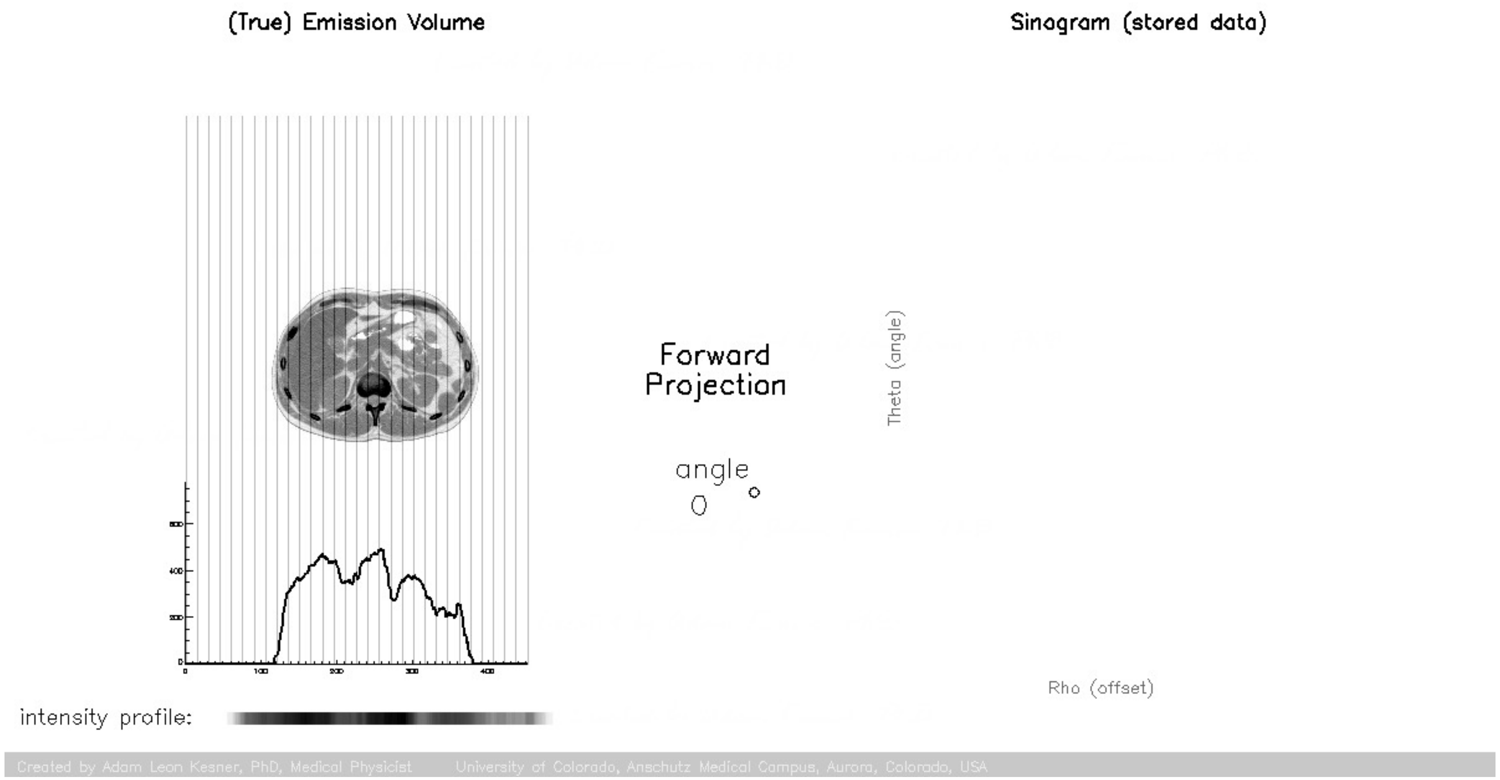
Computed Tomography





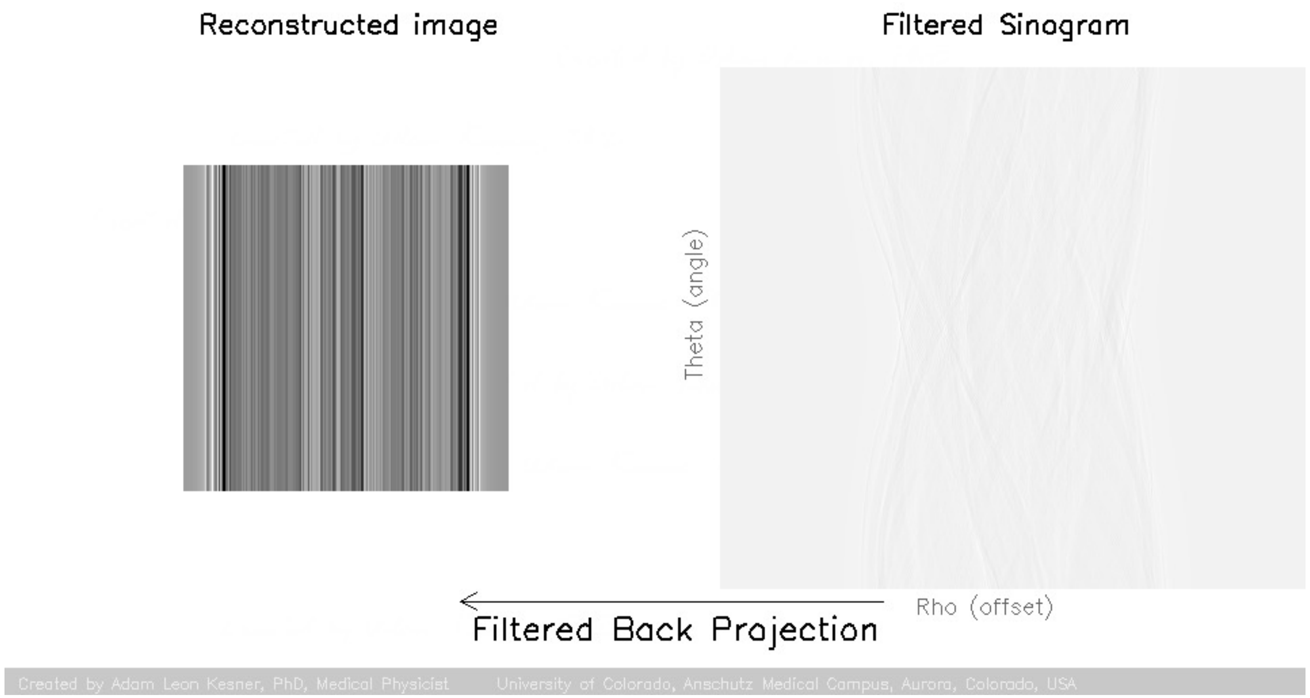
CT

- CT is measuring how much radiation is absorbed in the target



CT

- Image is represting how much signal is attenuated in each voxel vokselissa
- Attenuation is described by Hounsfield units



Computed Tomography

Computed Tomography

https://www.youtube.com/watch?v=TWU-nB4l5dU

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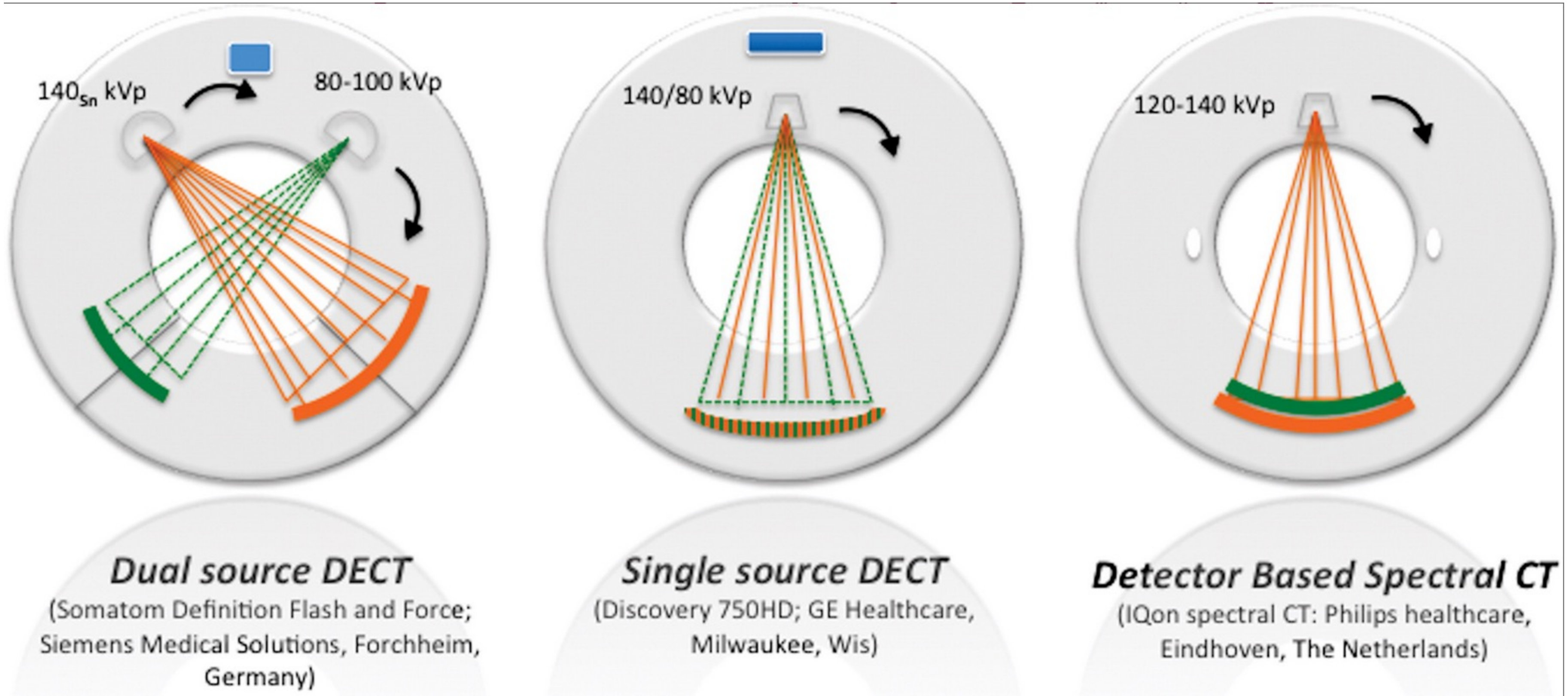
Computed Tomography
Dual Energy



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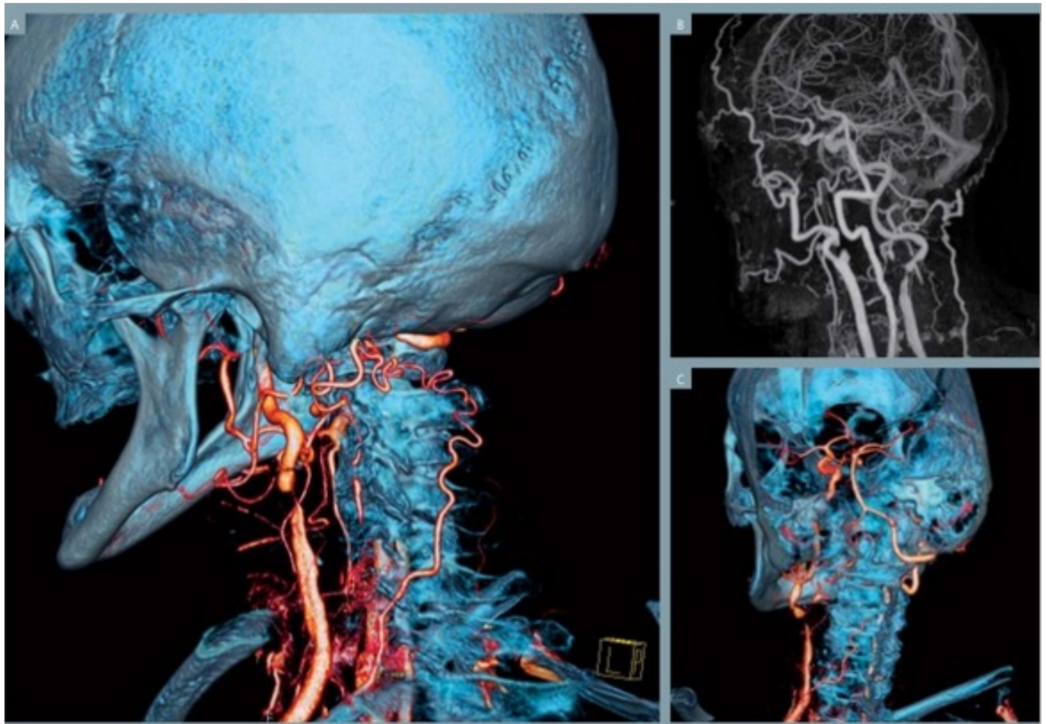
Computed Tomography
Dual Energy



Modern X-ray based imaging modalities
Radiography

Modern X-ray based imaging modalities
Mammography, Dental x-ray

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Modern X-ray based imaging modalities
Angiography

Modern X-ray based imaging modalities - Angiography

Check this example of Diagnostic Cerebral Angiography

https://www.youtube.com/watch?v=JJyf2lvB-Ps

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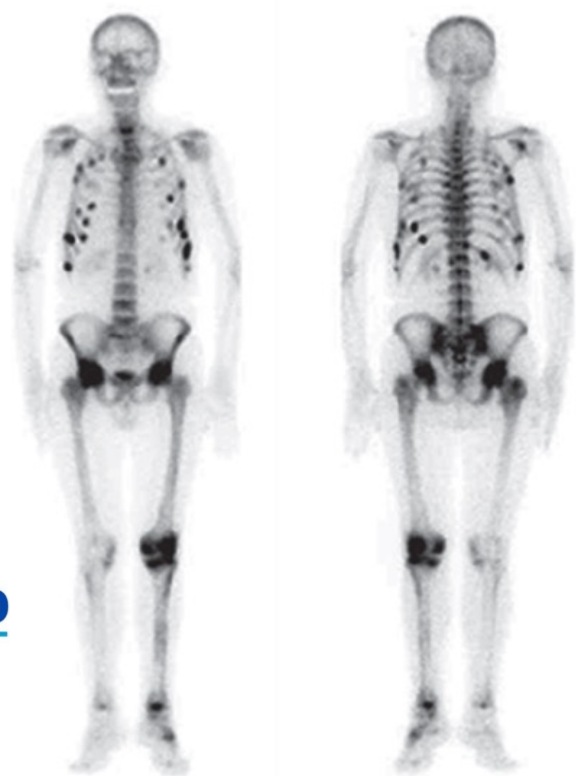
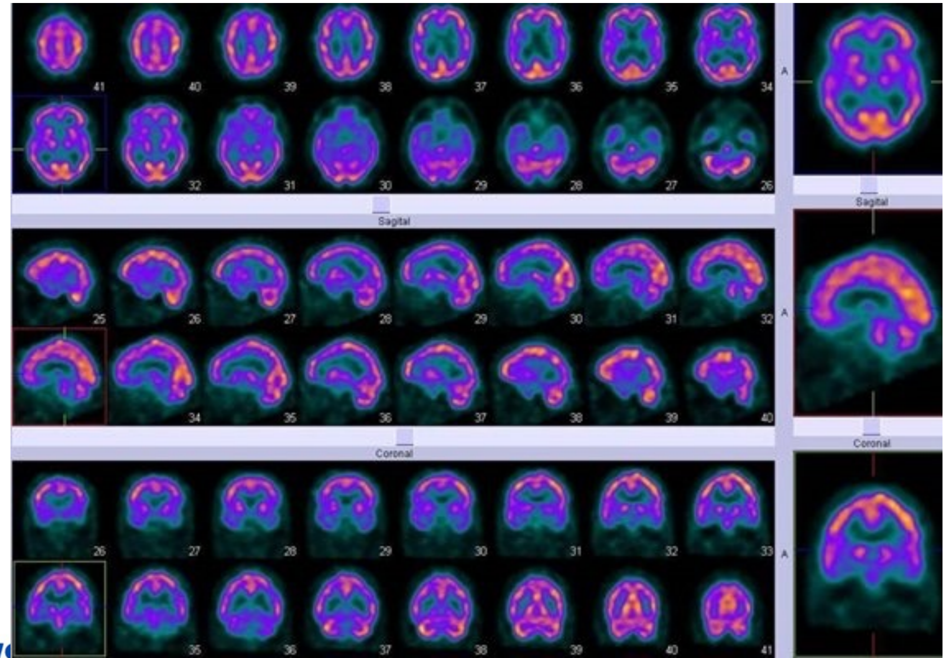
Nuclear Medicine

Nuclear Medicine studies (also called radionuclide scanning) were first done in the 1950s using special gamma cameras. Nuclear medicine studies require the introduction of very low-level radioactive chemicals into the body. These radionuclides are taken up by the organs in the body and then emit faint radiation signals which are measured or detected by the gamma camera.



Nuclear Medicine

SPECT uses a geometry similar to a CT scanner to form an image of the concentration of a radiopharmaceutical compound.



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Ultrasound scanning

In the 1960's the principals of sonar (developed extensively during the second world war) were applied to diagnostic imaging. The process involves placing a small device called a transducer, against the skin of the patient near the region of interest, for example, the kidneys. This transducer produces a stream of inaudible, high frequency sound waves which penetrate into the body and bounce off the organs inside. The transducer detects sound waves as they bounce off or echo back from the internal st ructures and contours of the organs. These waves are received by the ultrasound machine and turned into live pictures with the use of computers and reconstruction software.

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Magnetic Resonance

MR principals were initially investigated in the 1950s showing that different materials resonated at different magnetic field strengths. Magnetic Resonance (MR) Imaging (also know as MRI) was initially researched in the early 1970s and the first MR im aging prototypes were tested on clinical patients in 1980. MR imaging was cleared for commercial, clinical availability by the Food and Drug Administration (FDA) in 1984 and its use throughout the U.S. has spread rapidly since.

Countless scientists have been involved in the innovation of magnetic resonance. The development of MR imaging is attributed to Paul Lauterbur and scientists at Thorn-EMI Laboratories, England, and Nottingham University, England.

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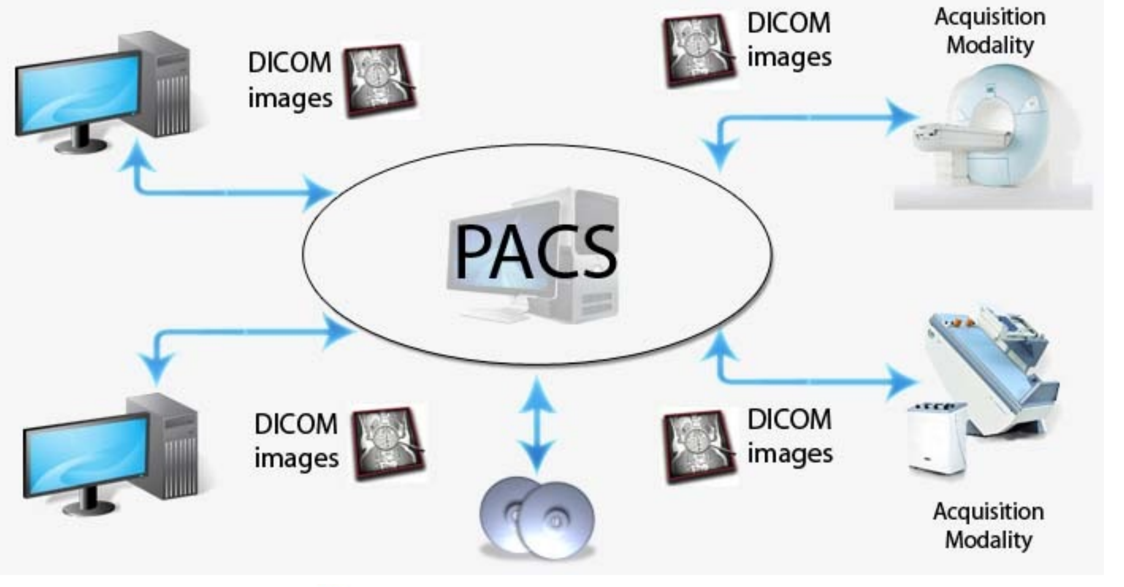
PACS – Picture Archiving and Communications System

Medical images are nowadays archived in PACS.



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Not just imaging for diagnostics, but essential part of treatment processes as well

Case example

Magnetic Resonance-guided Focused Ultrasound (MRgFUS)

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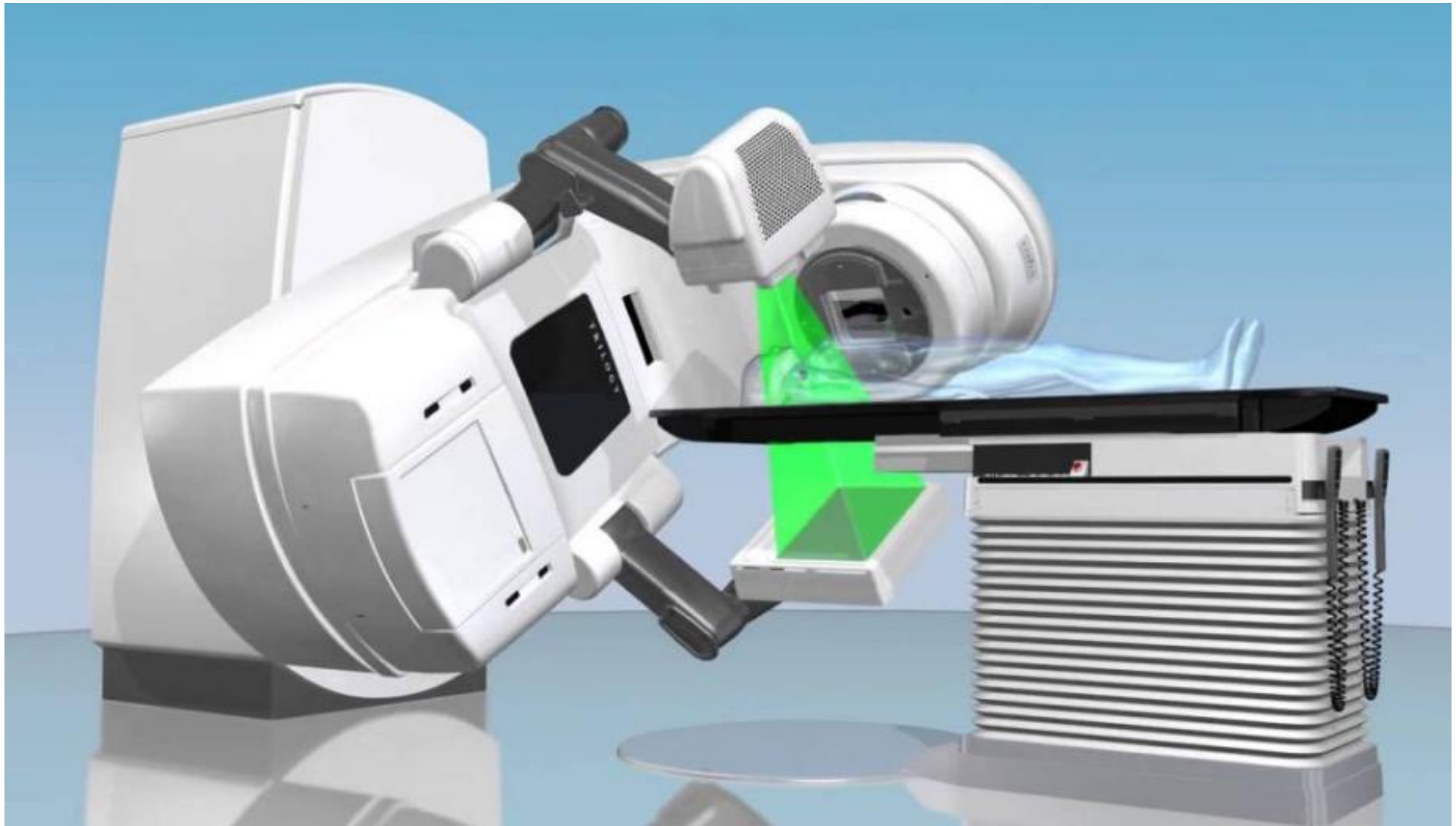

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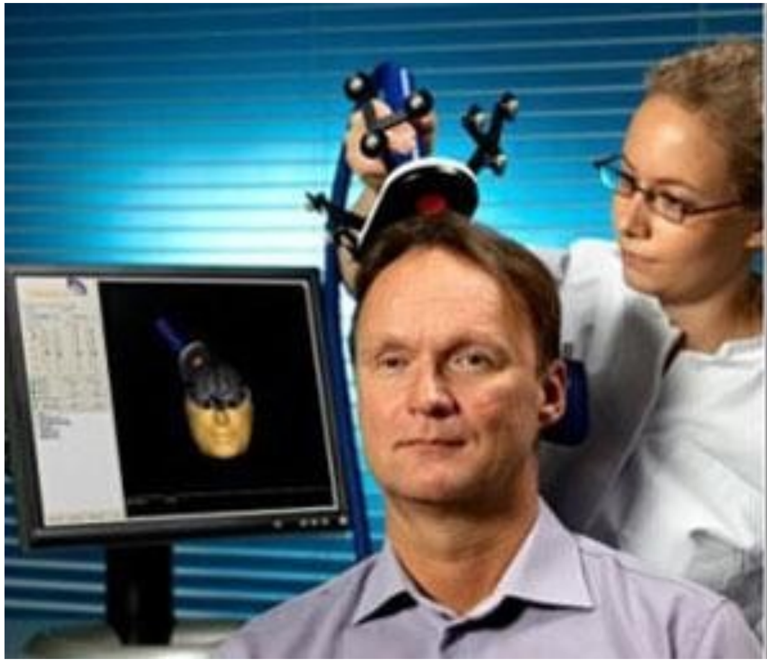

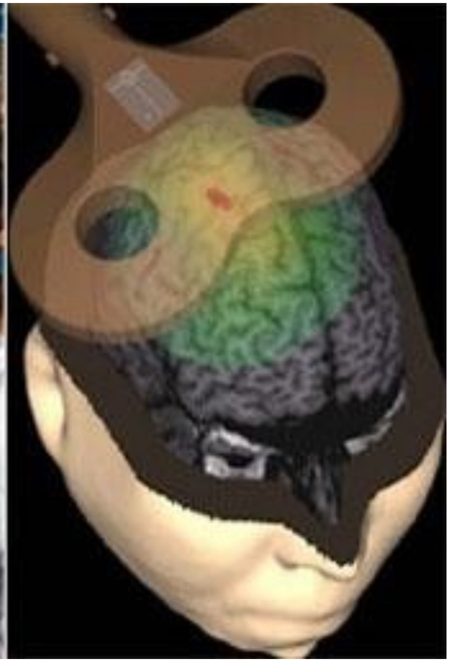

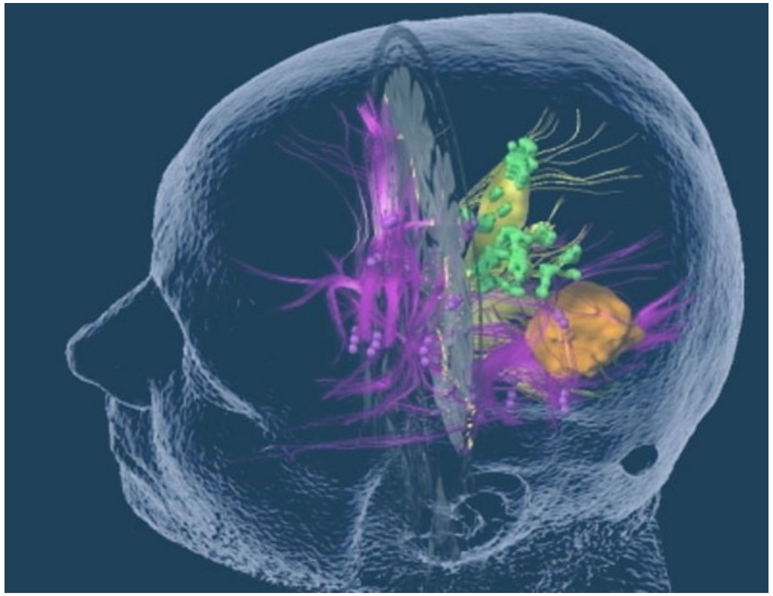

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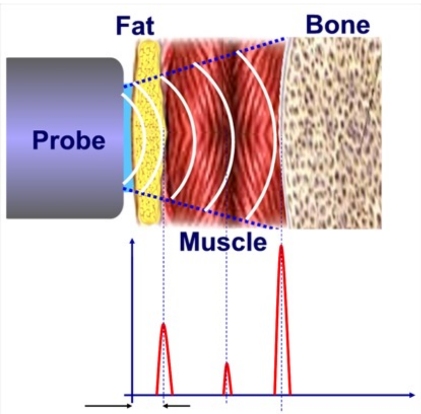
Medical Imaging using Ultrasound vs High Intensity Focused Ultrasound

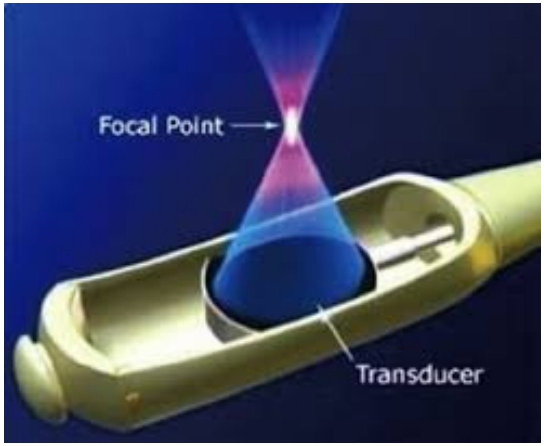
IMAGING

- Short pulses (1-5 ms)
- Frequency: 1-20 MHz
- Intensity: 1-180 W/cm ^{2}
- Pressure: 1-3 MPa

HIFU

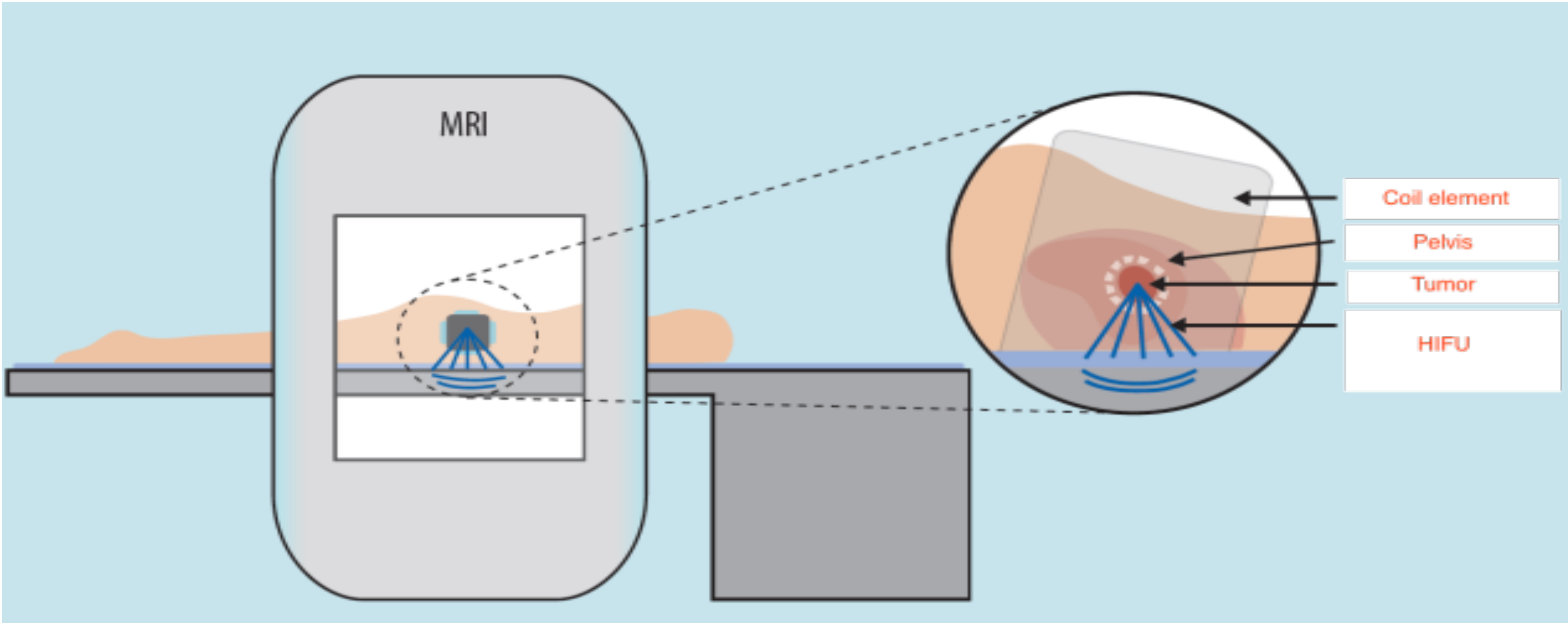
- Continuous transmission(16-76 s)
- Frequency: 1,2 MHz tai 1,4 MHz
- Intensity: 500-5000 W/cm ^{2}
- Pressure: 1-10 MPa





Philips 3T MRI + Sonalleve MRgFUS treatment system

Philips 3T MRI + Sonalleve MRgFUS treatment system



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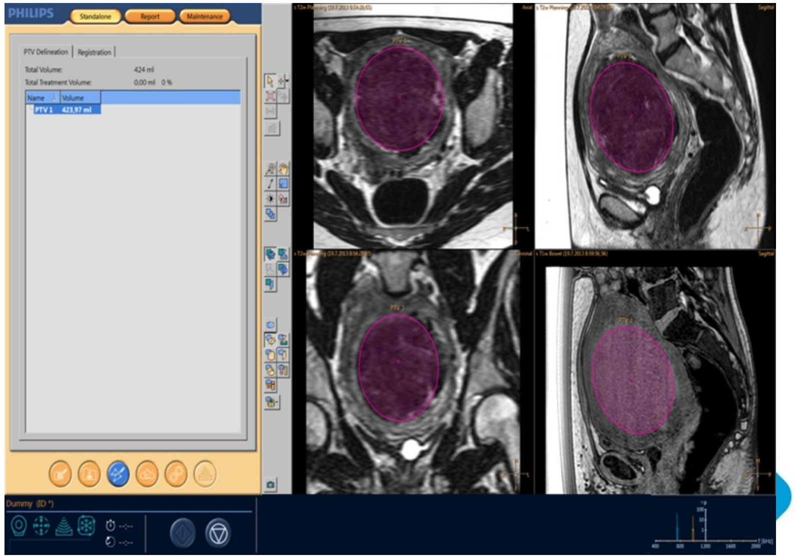
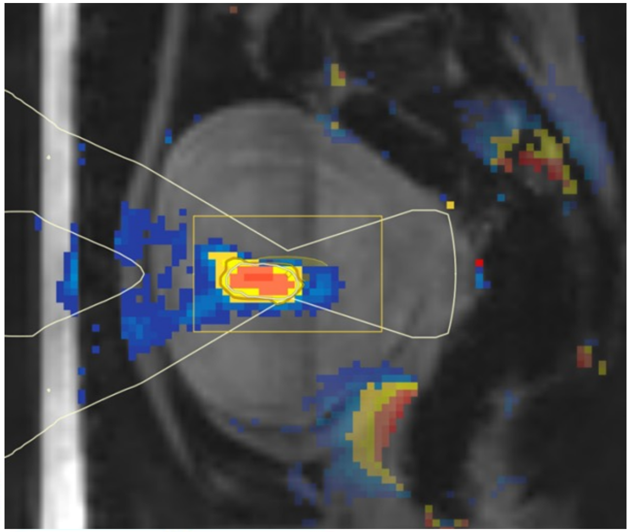
MRgFUS treatment of uterine fibroid

1. *Anatomical 3D MR image is used for treatment planning*
2. *“Treatment cells” are treated (heated to 57C) one by one*
3. *Result is evaluated from contrast enhanced MRI*





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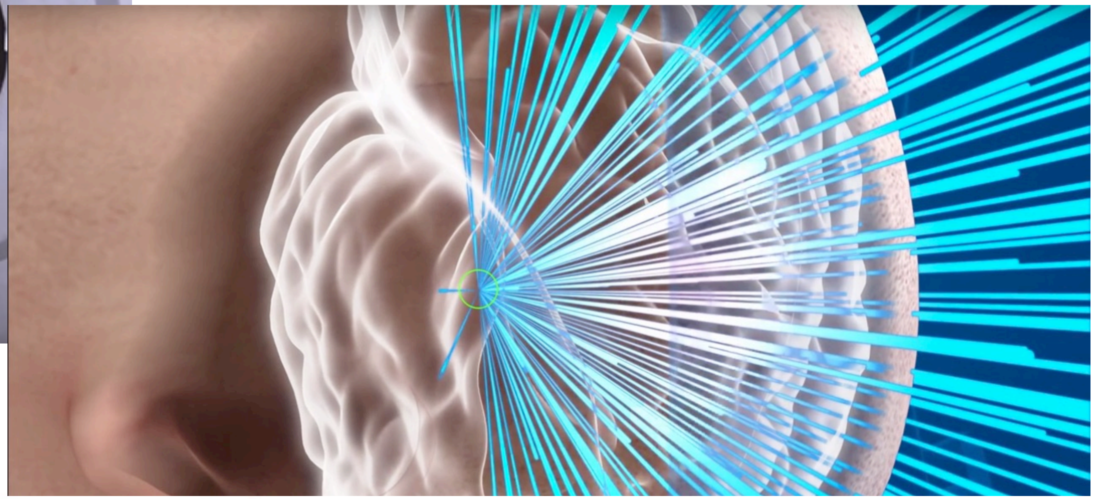
https://insightec.com/exablate-neuro/

https://www.fusfoundation.org



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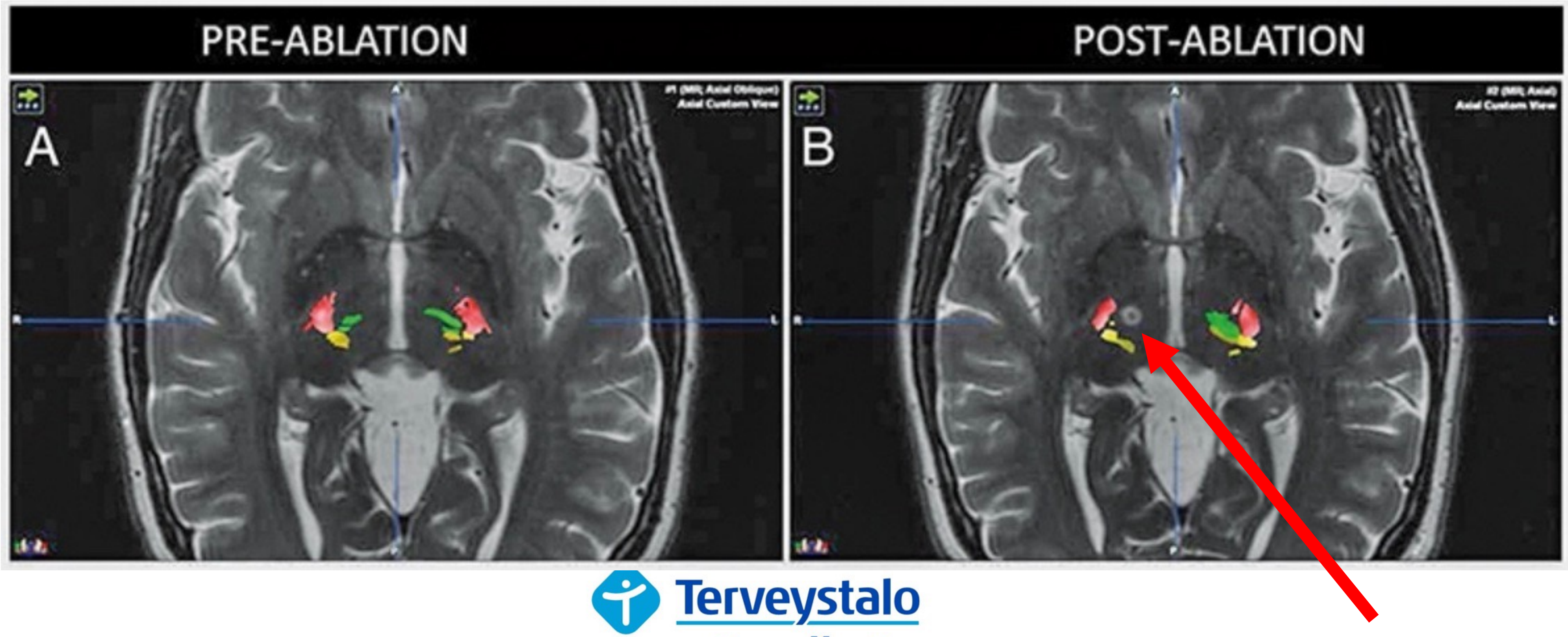
Not just imaging for diagnostics, but essential part of treatment processes as well



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AI in radiology

"We should stop training radiologists right now!"

Posted on May 19, 2018

"They should stop training radiologists now. It's just completely obvious within five years that deep learning is going to do better than radiologists. It might take ten years, but we've got plenty of radiologists already. I said this at a hospital, and it didn't go down to well."

— deep learning expert Geoff Hinton, 2017

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AI in radiology

‘AI will not replace radiologists; yet, those radiologists who take advantage of the potential of AI will replace the ones who refuse this crucial challenge.’ - by Filippo Pesapane et.al.

Eur Radiol Exp. 2018;2(1):35

Examples of tools assisting radiologist in decision making:

https://www.brainomix.com/stroke/e-aspects/
https://www.siemens-healthineers.com/en-eg/medical-imaging/digital-transformation-of-radiology/ai-in-radiology

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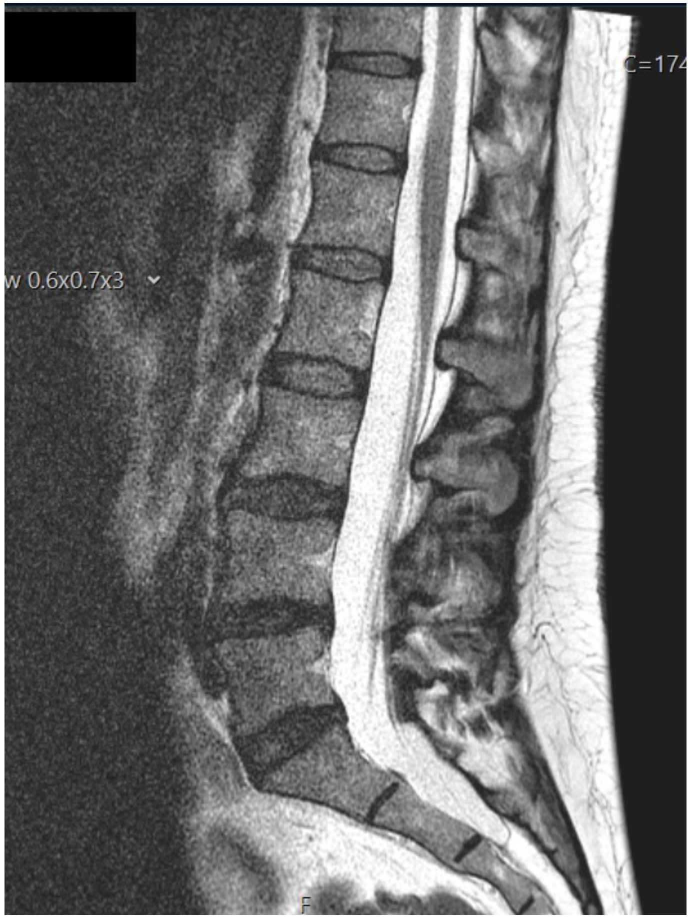

AI in MRI image reconstruction

T2 FSE Sag

Resolution:
0,6x0,7x3,0 mm3

Sequence duration:
1:57A

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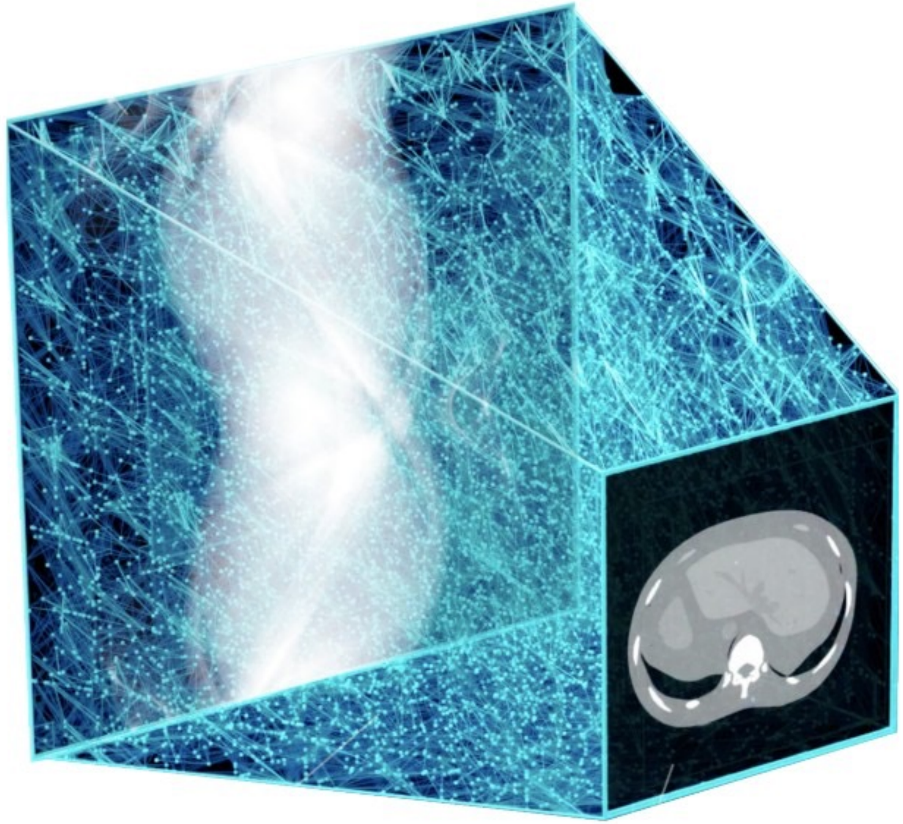
AIR Recon DL

More info: https://arxiv.org/abs/2008.06559

AI in Computed Tomography (CT) systems



Introducing a new era of image reconstruction.