Advances in Image Guidance with Emphasis on X Ray-Based Modalities

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Disclosures

- No conflict of interest

- Commercial product images/descriptions do not imply endorsement

Learning Objectives

- Review history of image guidance in radiation therapy
- Provide an overview of current image guidance devices and techniques
- Learn the latest advances in mage guidance
- Learn the applications of IGRT in specialty delivery units

Outline

- History of Image Guidance in Radiation Therapy
- Current Image Guidance Devices and Techniques
- Advances in Image Guidance
- Future Developments
- Summary

- **1940s** ---- Orthovoltage rotation therapy with fluorescent imaging
- **1950s** ---- Megavoltage portal imaging using radiographic film
- **1950/60s** ---- Megavoltage therapy with fluorescent imaging
- **1950/60s** --- Addition of kV x-ray tubes to megavoltage units
- **1980s** ---- Electronic portal imaging devices
- **1990s** ---- Room-mounted kV imaging systems
- **1990s** ---- Megavoltage CT, Electronic transponders, ultrasound
- **1990s/2000s** ---- Kilovoltage CBCT
- **2000s** ---- Optical systems/Surface imaging
- **2010s** ---- MR guidance
- **2020s** ---- PET guidance

Inter-fraction monitoring

Intra-fraction monitoring

Beam modulation/margin reduction

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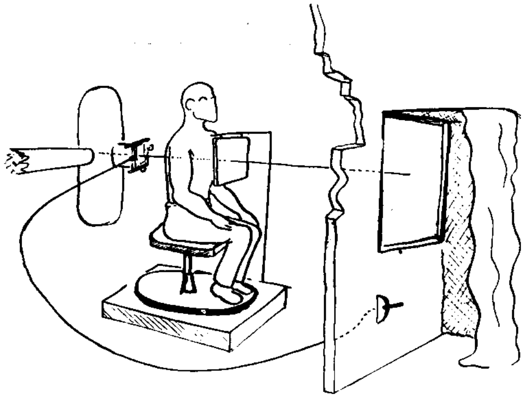
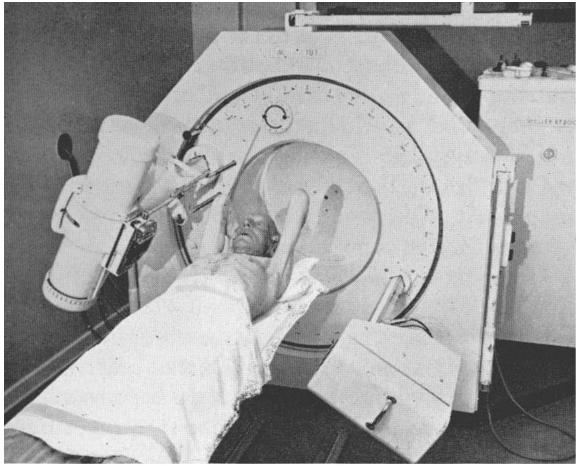
Early “IGRT” Systems-Orthovoltage Units



Nielsen and Jensen, Acta Oncologica 23: 51-66 (1942) –Remote beam adjustment

https://www.historad.com/en/
circa 1950 – Remote beam adjustment



Strandqvist and Rosengren, Br. J. Radiol. 31: 513-514 (1958) –Remote translational couch movement

Early “IGRT” Systems-Megavoltage Units

FIG. 1. The target room. From left to right: the collimating device of the 2 mev. Van de Graaff accelerator, the patient in the rotating chair, and the fluorescent screen, orthicon, and signal amplifier.

Continuous Visual Monitoring of a 2 MeV Roentgen Therapy, Am. J. Roent. Radium Ther. Nucl. Med. 1958

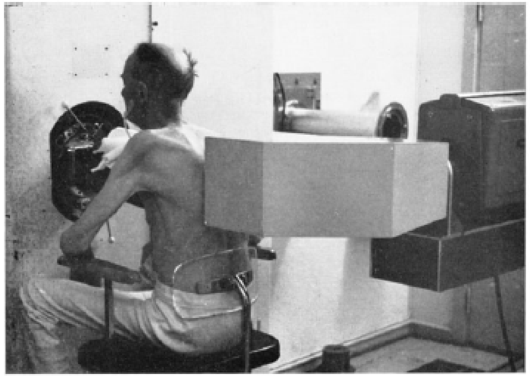


Fig. 1. 30 MV x-ray television. Patient in front of betatron at Det Norske Radiumhospital, Oslo, Norway, 16 December 1961. Patient has swallowed a 5 mm diameter plastic tube containing bits of tungsten separated by cotton. The lead-backed screen is behind the patient, and the fluoroscopic image is picked up by the high-sensitivity image orthicon television camera on the right.

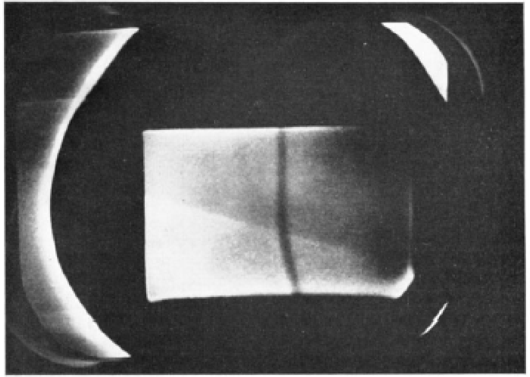
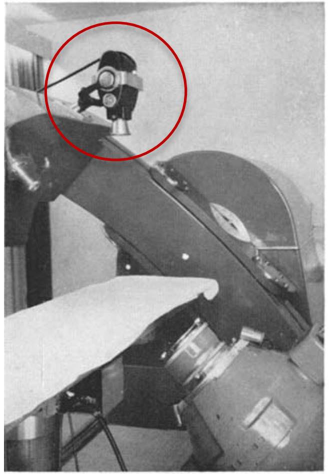


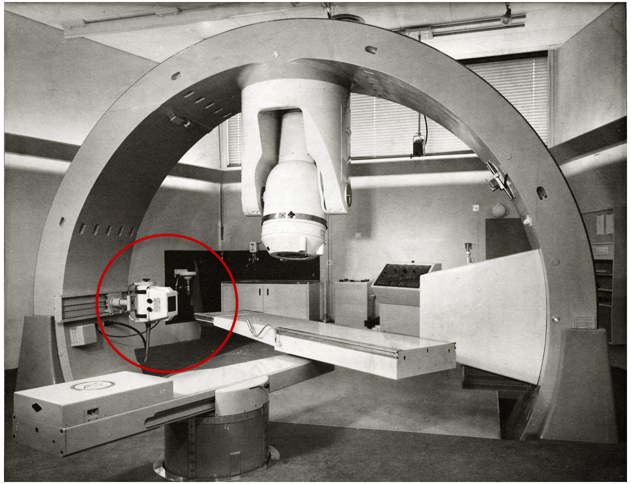
Fig. 2. X-ray television image at 30 MV of lead strip in oesophagus of phantom.

Television Monitoring of a 30 MV X-ray Beam, Benner et al. PMB 1962

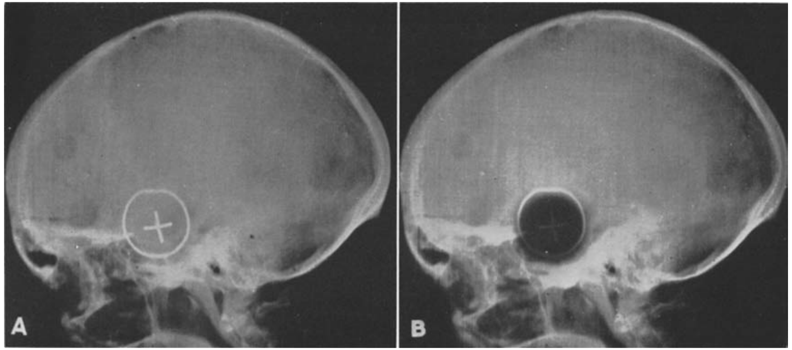
Early "IGRT" Systems-kV/MV Imaging



Holloway, Br. J. Radiol. 104:197-200 (1958) - X-ray tube attached to the counterweight



https://www.historad.com/en/
Circa 1960, NKI – X-ray tube/image receptor orthogonal to Cobalt beam



Weissbluth et al. Radiology 72: 242-253 (1959) - Retractable x-ray tube in front of MV beam aperture A) kV radiograph, B) kV/MV imaging

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X-Ray Based Imaging

2D Acquisition

- Electronic Portal Imaging Device (EPID)
  - All C-arm linacs, 6, 6 FFF & 2.5 MV
- Gantry-mounted kV digital radiography
  - All C-arm linacs, Zap-X, Akesis Galaxy RTi, …
- Room-mounted kV imaging
  - CyberKnife, ExacTrac, …

3D Acquisition

- Kilovoltage CBCT
  - All C-arm linacs, GammaKnife Icon, Halcyon, Akesis Galaxy RTi, medPhoton imaging ring
- Kilovoltage CT
  - CT-on-rail, Radixact, Reflexion
- Megavoltage CBCT
  - Halcyon
- Megavoltage CT
  - TomoTherapy/Radixact

Not a complete list!

Non X-Ray Based Imaging

- Ultrasound guidance
  - Best Sonalis, Elekta Clarity
- Electronic transponders
  - Calypso, RayPilot
- MR guidance
  - ViewRay MRIdian, Elekta Unity
- Surface guidance
  - Vision RT AlignRT, C-RAD Sentinel/Catalyst, Varian Identify

Kilovoltage CBCT

- C-Arm Linacs (Varian and Elekta)
  - Range of kVp, mAs, … protocols
- GammaKnife Icon
  - 90 kVp, 0.4 and 1.0 mAs
- Varian Halcyon
  - Range of kVp, mAs, … protocols
- Akesis Galaxy RTi
- medPhoton Imaging Ring



Kilovoltage CT

Helical kVCT-Radixact

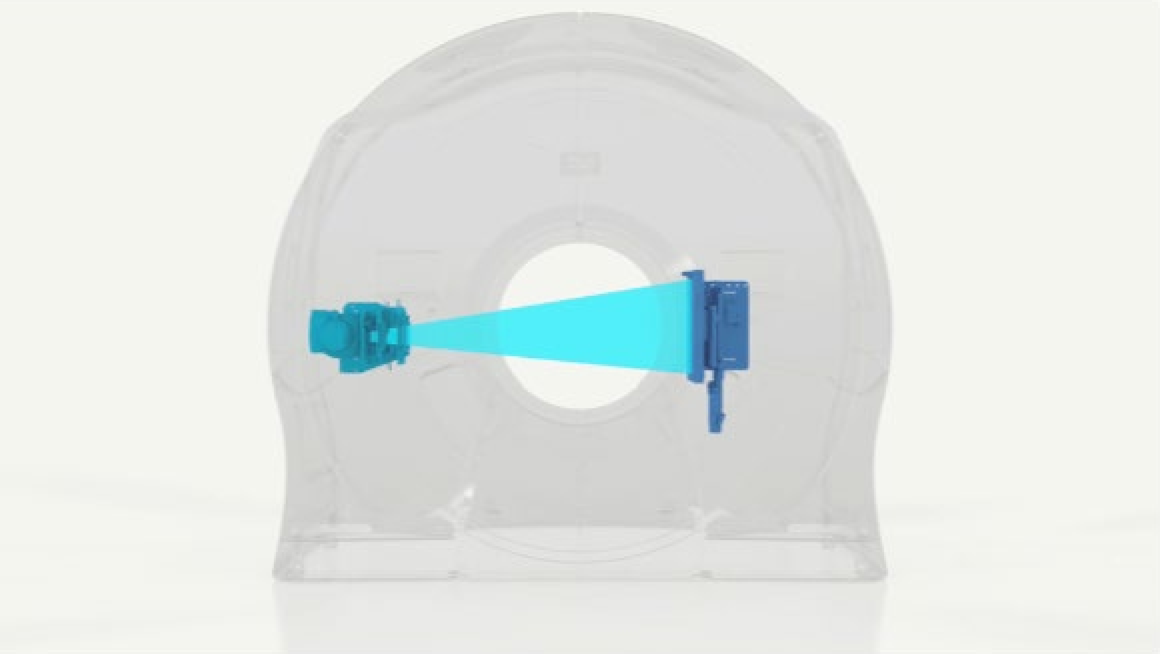


Image Courtesy Accuray

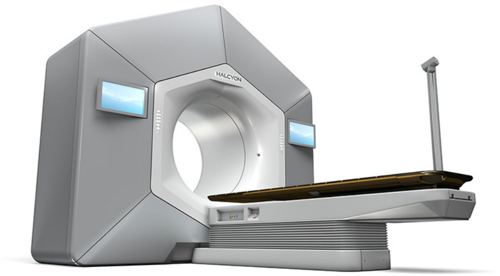
Up to 140 kVp
FOV: 27, 44, 50 cm

Up to 135 cm
Scan length

Megavoltage CT & CBCT

- Radixact/TomoTherapy (MVCT)
  - 3.5 MV FFF beam (fine, normal, coarse pitch)

- Varian Halcyon (MV CBCT)
  - 6 MV FFF beam



Imaging in Proton Therapy

- One of the first radiation modalities to employ in-room imaging using orthogonal x rays (~1970s)
- Gantry-mounted CBCT commercially available in 2010s
- CBCT units implemented on Proton units have SAD and SID larger than those on linacs, hence lower scatter but need higher tube current

Landry and Hua, *Med Phys* 45, e1086-e1095, 2018

Imaging in Proton Therapy

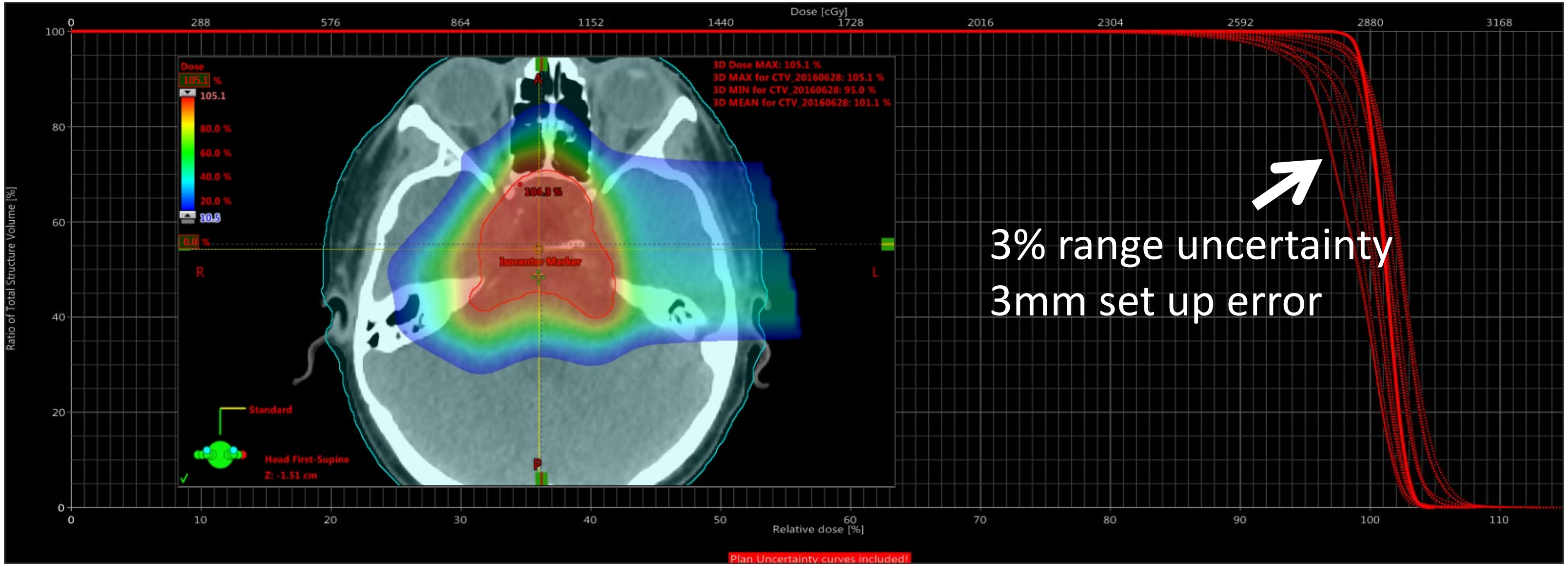
Variety of x ray-based systems: CT-on-Rail, CBCT (gantry/nozzle/couch mounted), robotic c-arm CBCT, SGRT

Landry and Hua, *Med Phys* 45, e1086-e1095, 2018

FIG. 2. (a) Varian gantry mounted CBCT at Scripps Proton Therapy Center (only one of the two flat panel detectors was used for CBCT) (b) IBA nozzle mounted CBCT (c) Hitachi C-arm mounted CBCT at St. Jude Children Research Hospital (d) Siemens in-room CT requiring couch rotation at the IBA gantry equipped APSS in Trento, Italy (e) Toshiba in-room CT with no couch rotation at the i-ROCK fixed beam line carbon ion facility of the Kanagawa Cancer Center (f) medPhoton ImagingRing couch-mounted CBCT at MedAustron's IR3, a fixed carbon ion/proton beamline room.

Importance of Imaging in Proton Therapy

- Proton dose distributions are sensitive to patient setup and anatomical changes along the beam path
- Imaging can help mitigate the degradation in dose delivered



Courtesy Chia-Ho Hua, St. Jude Children's Hospital

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Advances in Image Guidance

- Newer IGRT methods are often multi-modality (x-rays, optical cameras, may use fiducials,…)

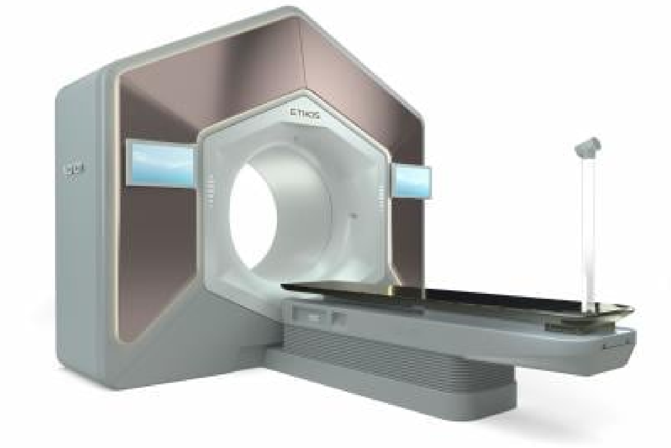
- X-ray imaging (kV/MV) along with optical imaging is an integral part of target tracking (robotic/gimbaled gantry, MLC tracking, couch tracking) and plan adaptation

Triggered Imaging/Auto Beam Hold - Varian

- Utilized for real-time target tracking
- Involves multiple kV imaging during treatment, triggered by elapsed time, MU delivered, gantry angle, or motion
- Often requires fiducials
- Auto beam hold searches for implanted fiducials within the images and pauses the treatment if needed

Online Adaptive Therapy – Varian Ethos

- kV-CBCT-based plan adaptation
- Day-of-treatment iterative CBCT used to create an adaptive plan



Reactive Target Tracking - CyberKnife Synchrony

Image Courtesy Accuray

Proactive Target Tracking – CyberKnife Synchrony

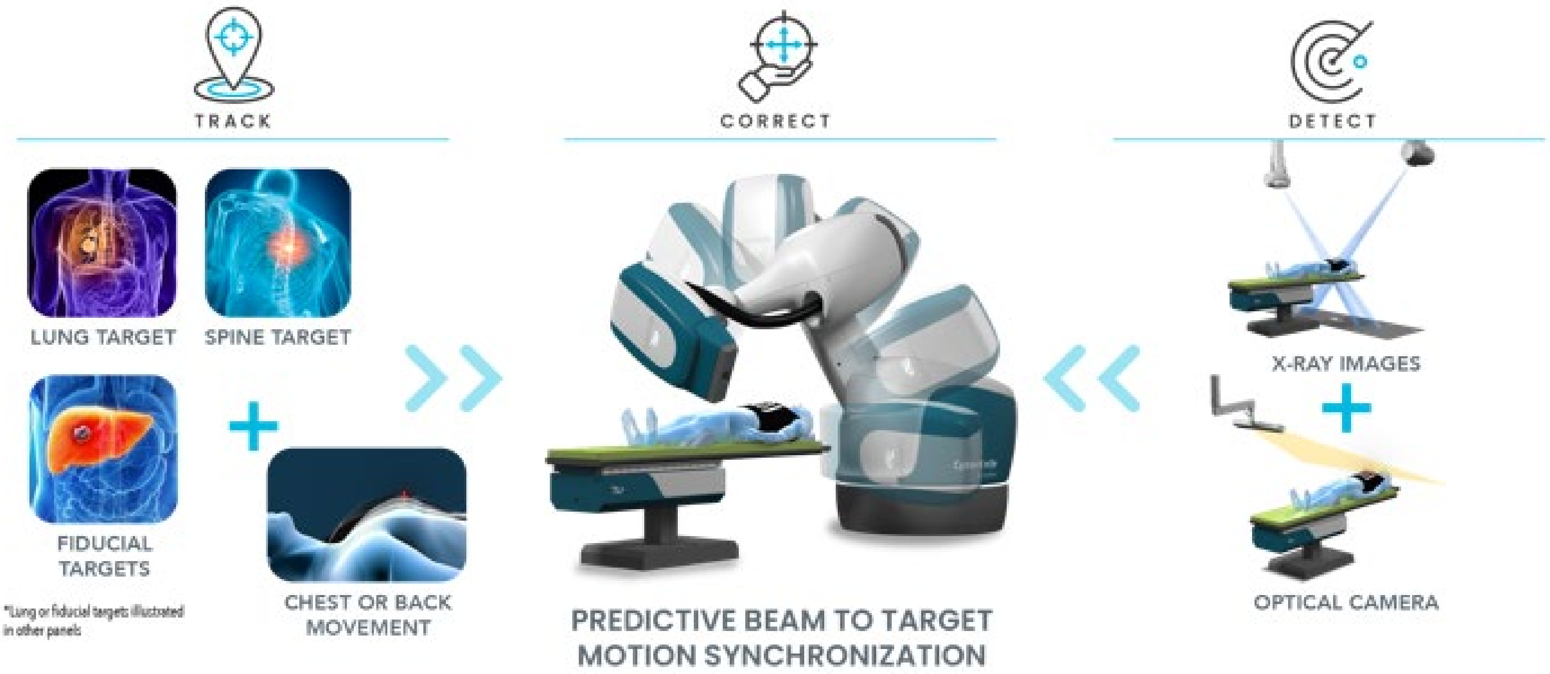
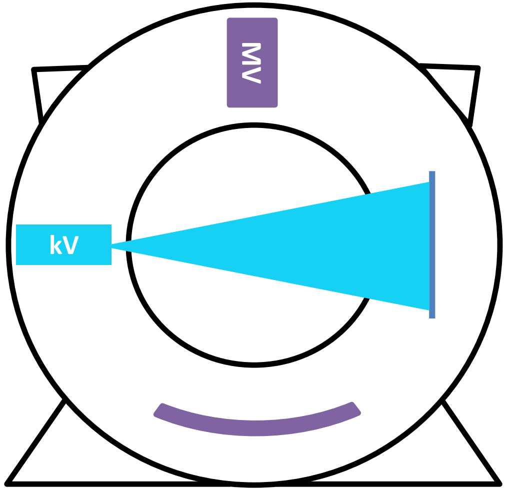


Image Courtesy Accuray

Target Tracking on Radixact

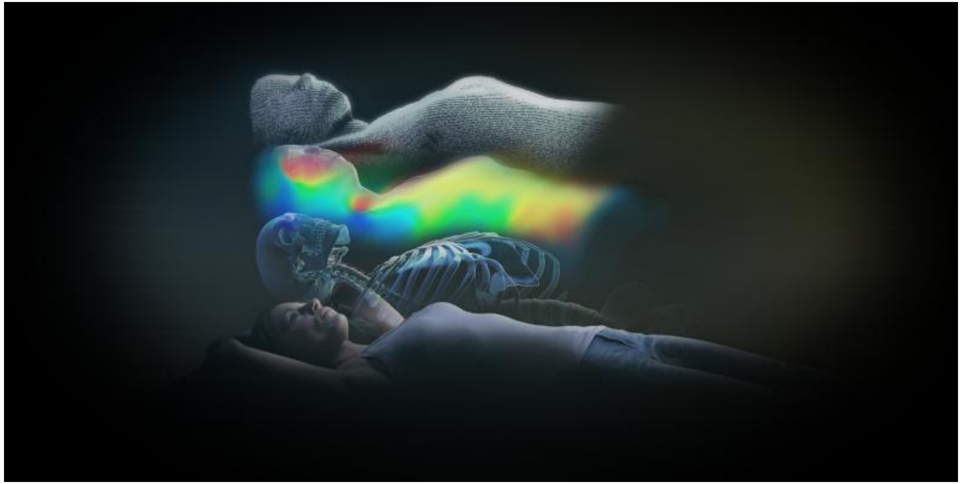
kV imaging enables in-treatment monitoring of target location
External camera enables real-time monitoring of breathing cycle



Images Courtesy Accuray

ExacTrac Dynamic

Combining thermal and surface imaging and x-ray tracking



Images Courtesy BrainLab

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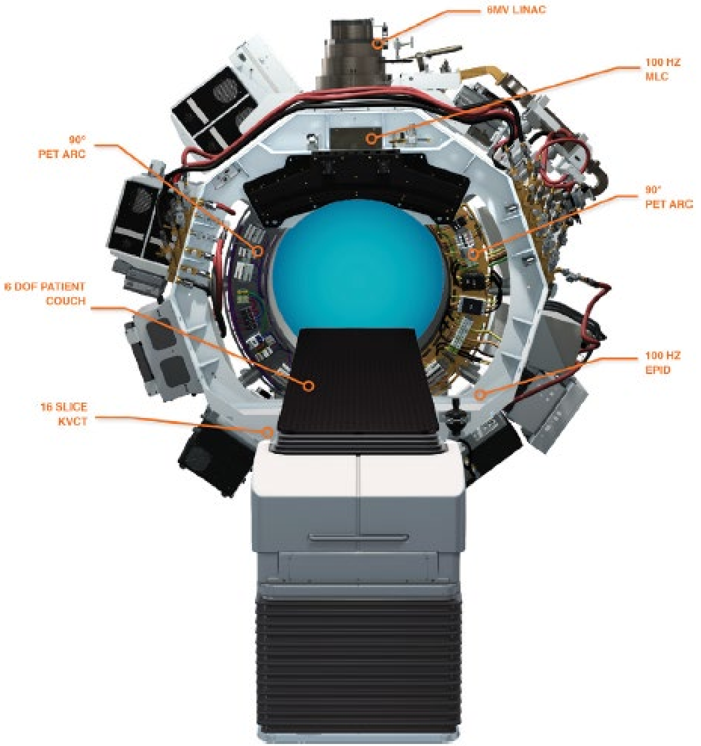
PET/Linac-Reflexion X1



Shirvani et al. *Br. J. Radiol.* 2020; 93: 20200873

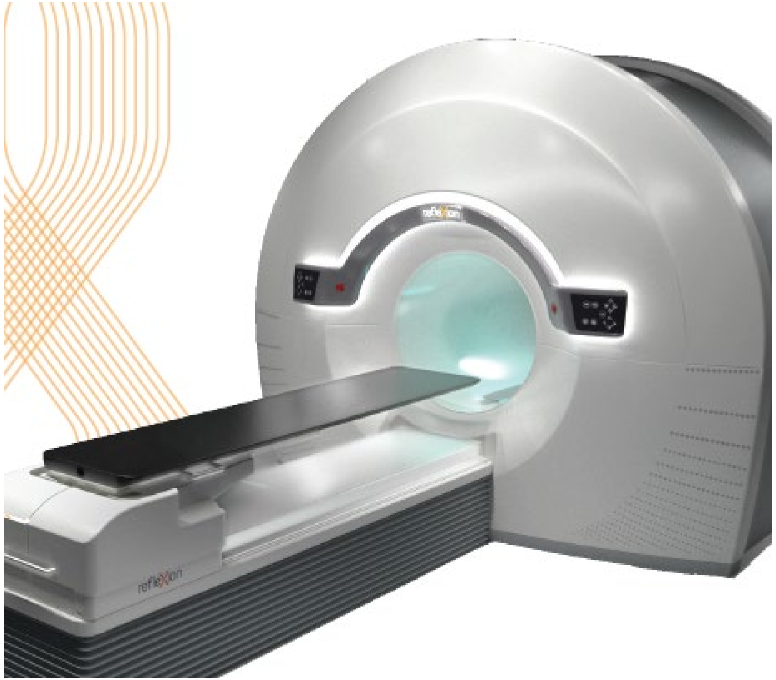
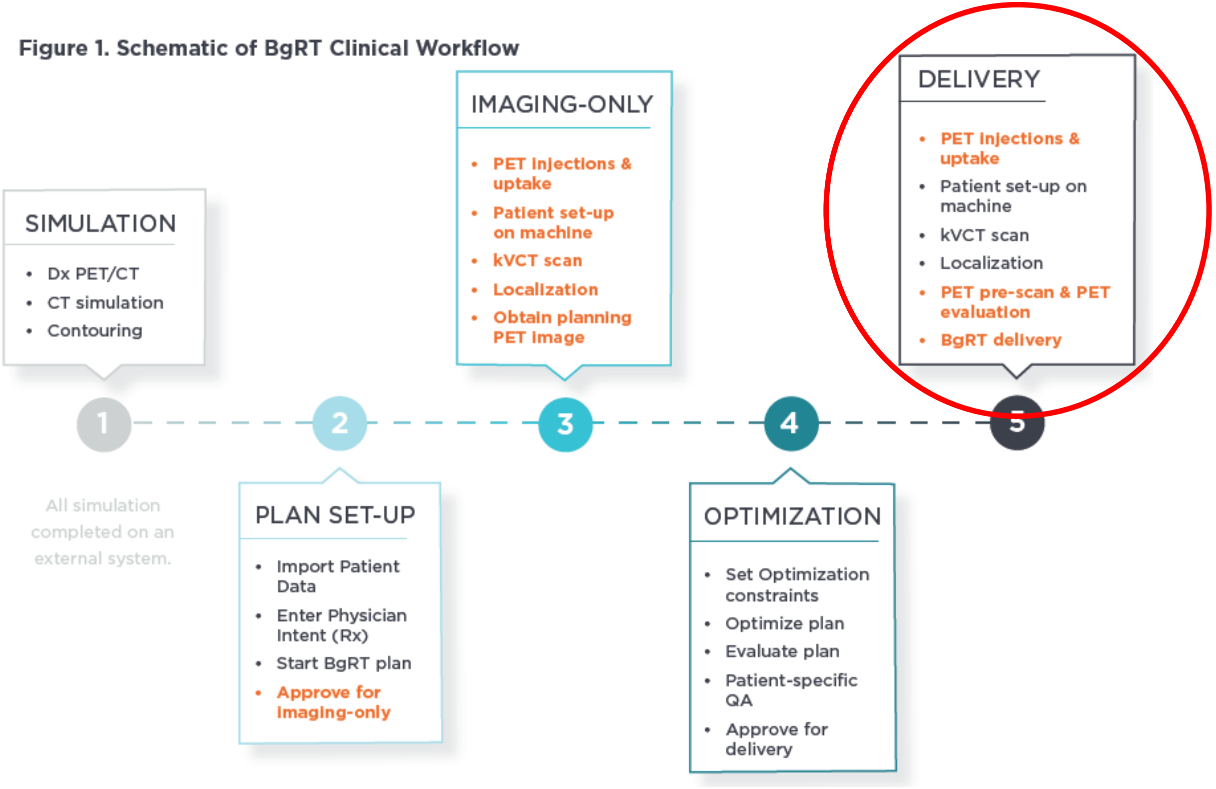


Image Courtesy Reflexion

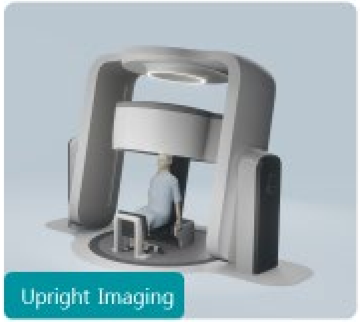
Biology-Guided Radiotherapy Process

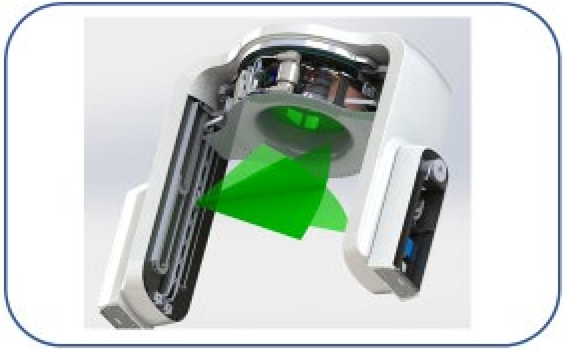


Two orthogonal PET arcs continuously acquire limited time sampled images which are used to control treatment delivery

Da Silva and Mazin, BgRT White Paper

Multi-Axis Computed Tomography





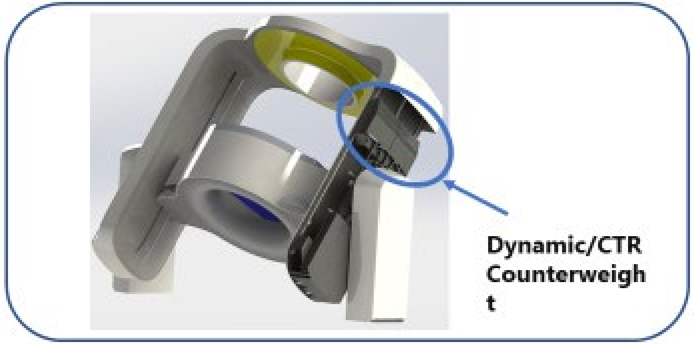


Image Courtesy Rock Mackie - Leo Cancer Care

Future Directions in Imaging in Proton Therapy

- Proton radiography - ProtonVDA system
- Proton CT - PRaVDA (Proton Radiotherapy Verification and Dosimetry Applications)
- ……

Summary

- Image guidance has evolved from inter-fraction to intra-fraction monitoring along with advancements in beam modulation, and often includes multimodality imaging
- The need to position the patient accurately (due to decreased margins) and monitor target movements during treatment delivery has become critically important
- X-ray based imaging will continue to play a role in IGRT for the foreseeable future

Conformal Treatments-IGRT's Role

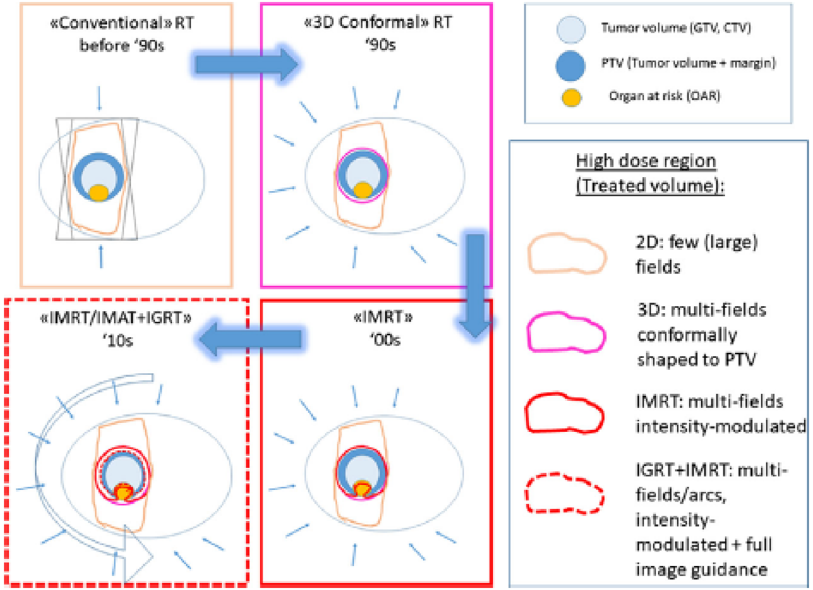
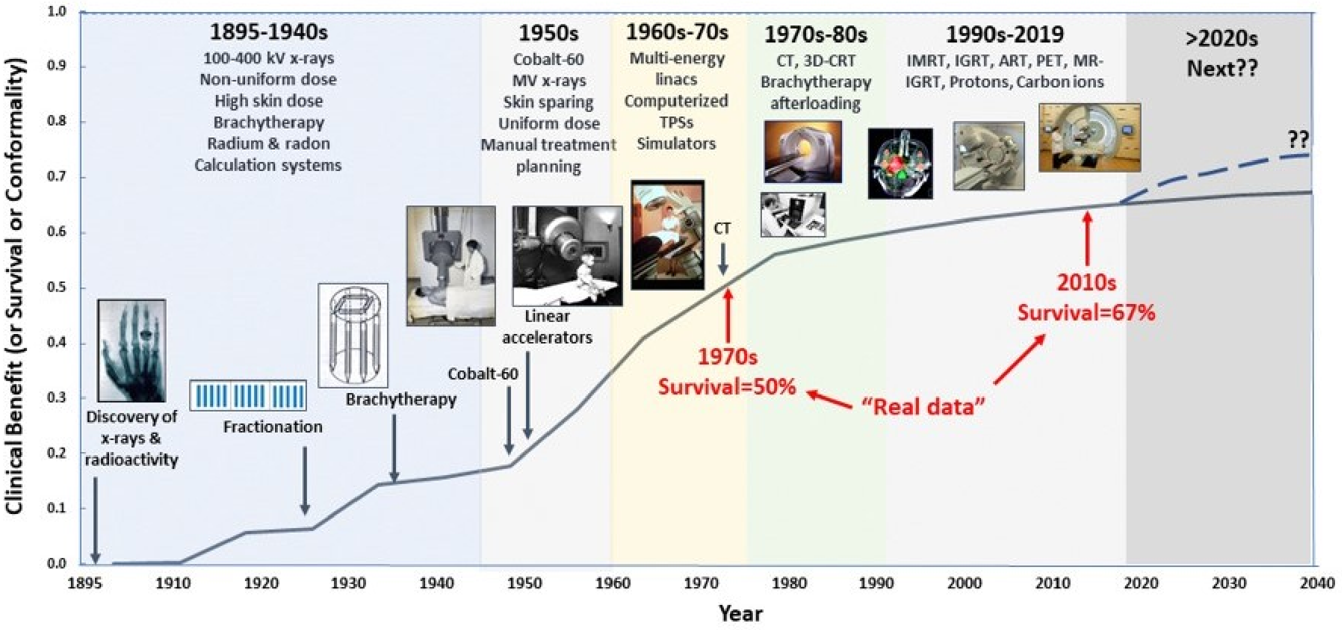


Fig. 1. Schematic plot of the impact of technology in the last decades in delivering dose distributions more tailored to GTV/CTV in a typical case of tumor next to an organ at risk: At each step, the high-dose region corresponding to the previous technologies is overlaid to better appreciate the net benefit. Nowadays, image-guided intensity-modulated radiotherapy (using multifields or arc, IMRT, and VMAT, respectively) may strictly tailor the prescribed dose distribution to the tumor, using reduced margins thanks to the high precision of the delivery permitted by IGRT.

Fiorino et al. *Mol Oncol.* 14(7): 1500-1513, 2020

Outcome Assessment-IGRT's role?



Van Dyk, The Modern Technology of Radiation Oncology, volume 4


Questions?