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

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SAM Therapy Educational Course, AAPM 63rd Annual Meeting, 2021
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 image 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
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<tr>
<th>Decade</th>
<th>Description</th>
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<td>1940s</td>
<td>Orthovoltage rotation therapy with fluorescent imaging</td>
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<td>1950s</td>
<td>Megavoltage portal imaging using radiographic film</td>
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<td>1950/60s</td>
<td>Megavoltage therapy with fluorescent imaging</td>
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<td>1950/60s</td>
<td>Addition of kV x-ray tubes to megavoltage units</td>
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<td>1990s</td>
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<td>1990s</td>
<td>Megavoltage CT, Electronic transponders, ultrasound</td>
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<td>1990s/2000s</td>
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<td>2000s</td>
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<td>2010s</td>
<td>MR guidance</td>
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<td>PET guidance</td>
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Inter-fraction monitoring
Intra-fraction monitoring
Beam modulation/margin reduction
Outline

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Early “IGRT” Systems-Orthovoltage Units


Early “IGRT” Systems-Megavoltage Units

Fig. 1. 30 MV X-ray television. Patient in front of betatron at Det Norske Radiumhospitalet, 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.


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

Fig. 2. X-ray television image at 30 mv of lead strip in oesophagus of phantom.
Early “IGRT” Systems-kV/MV Imaging

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

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

https://www.historad.com/en/
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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 MRIIdian, 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

Up to 140 kVp
FOV: 27, 44, 50 cm
Up to 135 cm
Scan length

Image Courtesy Accuray
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
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
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.

3% range uncertainty
3mm set up error

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

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