Imaging for Planning Verification: In room Imaging Pre-Treatment Verification

Niko Papanikolaou, Ph.D.
Professor and Director
CTRC and UTHSCSA

The Need for Imaging

- Accurate knowledge of patient anatomy is critical for both the planning and delivery of radiation
- Target localization is an essential component of IGRT and IMRT
- Treatment verification imaging can reduce systematic and random uncertainties and potentially improve outcomes
- Delivery and Imaging integration is necessary in order to achieve true IGRT delivery and optimize the treatment

Static Imaging

- Portal Images
  - Film
  - Electronic Portal Imaging Device (EPID)
- Computed Tomography (CT)
  - Kilovoltage
  - Megavoltage
  - Cone Beam (kV and MV)
- Digital Tomosynthesis (DTS)
- Ultrasound (US)

Dynamic Imaging

- Stereoscopic Imaging
- Radiofrequency Tracking
- Optical Tracking
- Video Tracking

Static Imaging

- Imaging done prior to treatment
- Daily images compared against reference images taken during initial setup
- Patient positioned according to calculated shifts
- Patient is treated
- Process repeated for subsequent fractions

Portal Film

- Quick method to obtain images
- Checked against projection images created from planning CT
- Bony anatomy usually used for registration purposes due to inherent low contrast of MV images.

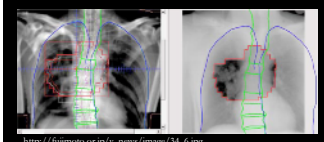
Portal Film

- Application
  - Any Region of the body
- Resolution
  - Sub-millimeter
- Pros
  - Cheap
  - Easy to implement
- Cons
  - Requires wet chemistry
  - Images not in digital format
  - Projection images – Loss of information in one dimension
  - Low soft-tissue contrast

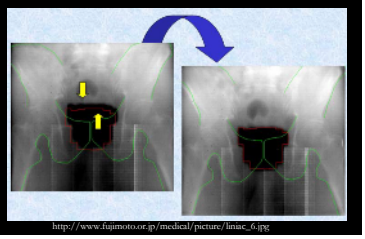
EPIDs

- CCD-based or Amorphous Silicon
- Images already in digital format – all digital image processing tools available
- Possibility of quick online registration using overlaid structure sets with automatic generation of shifts to align
- Possibility of performing online dosimetry

Examples of Portal Images



http://fujimoto.or.jp/y_news/image/34_6.jpg



http://www.fujimoto.or.jp/medical/picture/liniac_6.jpg

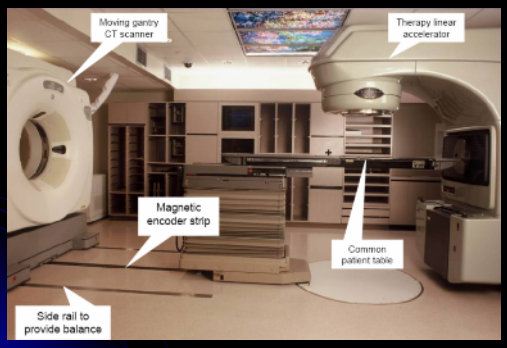
EPID

- Application
  - Any Region of the body
- Resolution
  - Sub-millimeter
- Pros
  - Images already in digital format – all image processing tools available
  - Can be retrofitted to existing linear accelerators
- Cons
  - Projection image – loss of information in one dimension
  - Low soft tissue contrast

CT - Kilovoltage

- kV CT is currently gold standard for planning purposes.
- Possibility of using a kV CT coupled with the patient treatment allows full use of automatic registration protocols to generate required shifts for patient alignment based on volumetric data
- CT-on-rails systems propose a conventional CT gantry built into treatment vault with a common couch for imaging and treatment

CT on rails



http://www.aapm.org/meetings/06SS/documents/Dong_In_room_CT_imaging.pdf

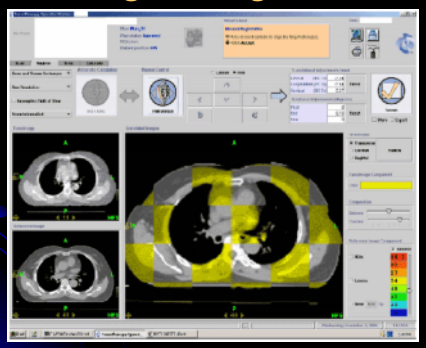
kV CT

- Application
  - Any Region of the body
- Resolution
  - Millimeter
- Pros
  - Gold standard in Radiotherapy
  - Volumetric information
  - Very good soft tissue contrast
- Cons
  - Specialized equipment required
  - Susceptible to artifacts from high Z materials
  - Equipment and room needs

CT -Megavoltage

- Currently only available with Tomotherapy HiArt linear accelerators.
- Automatic registration performed with further input possible by operator.
- Corrections available for all translations as well as rotations

Megavoltage CT



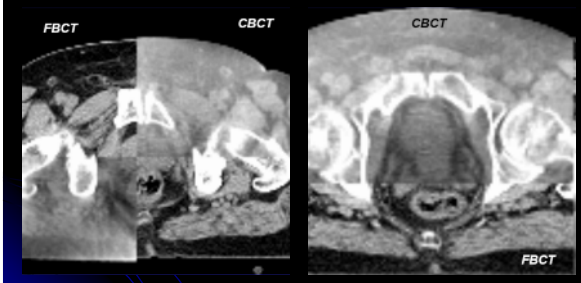
MV CT

- Application
  - Any Region of the body
- Resolution
  - Millimeter
- Pros
  - Imaging done with patient on treatment couch
  - Less susceptible to artifacts from high Z materials
  - Integrated in one system
- Cons
  - Only available with one modality
  - Lower soft-tissue contrast as compared to kV CT

Cone Beam CT – kV and MV

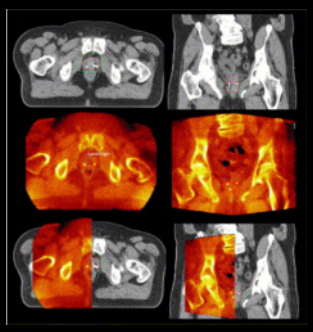
- Entire volume of interest is imaged in one rotation of source around patient.
- Cone Beam CT reconstruction uses approximate solution algorithms due to diverging beam in all directions.
- Imaging performed using kV x-ray head installed on gantry or using treatment beam itself in conjunction with a digital receptor.

kV Cone Beam CT



www.aapm.org/meetings/06SS/documents/Sonke**ConeBeam**.pdf

MV Cone Beam CT



Morin O, Gillis A, Chen J, Aubin M, Bucci MK, Roach M 3rd, Pouliot J. *Megavoltage cone-beam CT: system description and clinical applications.* Med Dosim. 2006 Spring;31(1):51-61.

Cone beam CT

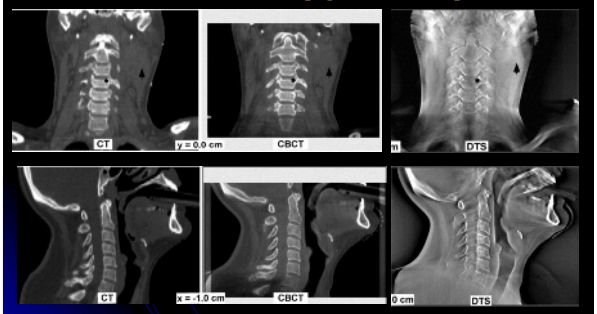
- Application
  - Any Region of the body
- Resolution
  - Millimeter
- Pros
  - Imaging done on treatment couch with common isocenter
  - Uses existing equipment
  - Reasonable soft-tissue contrast
- Cons
  - Reconstruction algorithms not exact
  - Limited Field of View

A lot of data are generated that we still do not know how or where to use

Digital Tomosynthesis (DTS)

- Digital version of conventional tomography
- Images acquired at different angles and structures not in plane of reconstruction are smeared to lower their contrast.
- Pseudo-tomographic images or pseudo-volumetric datasets can be reconstructed.
- Can be kV or MV based.

DTS – Therapy Example



Godfrey DJ, Yin FF, Oldham M, Yoo S, Willett C. *Digital tomosynthesis with an on-board kilovoltage imaging device.* Int J Radiat Oncol Biol Phys. 2006 May 1;65(1):8-15.

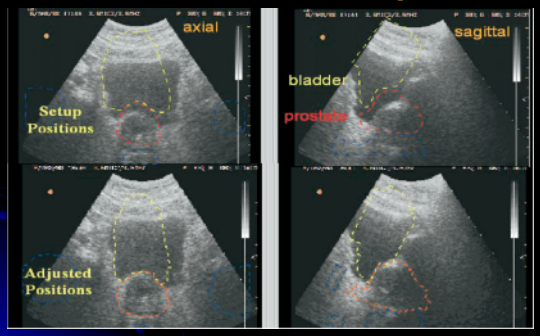
DTS

- Application
  - Any Region of the body
- Resolution
  - Millimeter
- Pros
  - Less dose than cone beam CT
  - Uses existing equipment
  - Imaging done in treatment position
- Cons
  - Reconstruction not truly 3-dimensional

Ultrasound

- Images acquired using external or intra-cavitary probes.
- Non-ionizing, true-volumetric data acquisition
- Planning structure sets can be overlaid to suggest shifts required for correct alignment
- Positional accuracy of 1-2 mm currently possible

Ultrasound Example



Fung AY, Ayyangar KM, Djajaputra D, Nehru RM, Enke CA. *Ultrasound-based guidance of intensity-modulated radiation therapy.* Med Dosim. 2006 Spring;31(1):20-9. Review.

Ultrasound

- Application
  - Any Region of the body that does not contain much air
- Resolution
  - Sub-millimeter
- Pros
  - No ionizing radiation
  - Independent system that can be used in any existing setting
- Cons
  - Image quality not as clear as other methods
  - Specific training required for technologists
  - Severe artifacts from air cavities

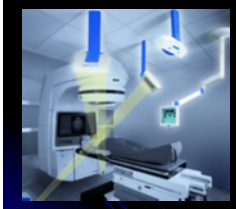
Dynamic Imaging

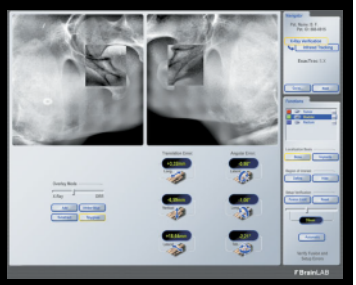
- Images acquired throughout treatment
- Treatment altered/interrupted if shifts larger than preset level is observed

Stereoscopic Imaging

- Two or more x-ray sources acquire images and online registration is performed to precisely deliver beam
- Can be combined with IR tracking
- Used as Cyberknife XSight and Brainlab ExacTrac systems.
- Can be used for gating or tumor tracking
- Submillimeter accuracy in both systems

Stereoscopic Imaging





http://www.uroa.com/images/BRAINLAB_IGRT.jpg
http://www.brainlab.com/download/psc/rscetx6dFull.jpg

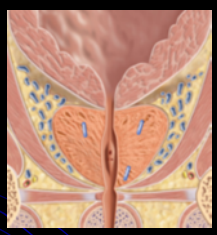
Stereoscopic Imaging

- Application
  - Any Region of the body
- Resolution
  - Sub-millimeter
- Pros
  - Can be retrofitted in current vaults
  - Good soft tissue contrast
- Cons
  - Based on projection images, not volumetric data
  - Rigid body assumption

Radiofrequency Tracking

- Small beacon transmitters are implanted into the patient (Calypso system).
- They are identified in the planning CT and their positions relative to the isocenter is calculated.
- During treatment, an array determines the positions of the transponders relative to isocenter.
- Real-time evaluation of position is obtained
- Sub-millimeter accuracy in tracking

Calypso



http://www.calypsomedical.com/products/default.asp

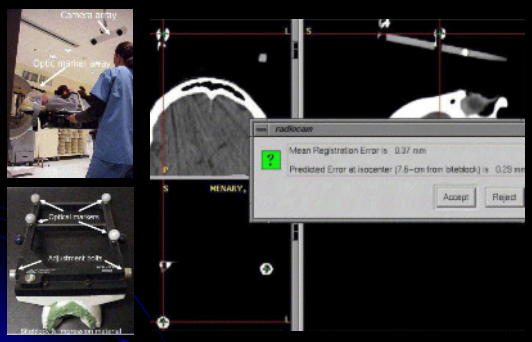
Calypso System

- Application
  - Prostate
- Resolution
  - Sub-millimeter
- Pros
  - Independent system that can be retrofitted to existing facilities
- Cons
  - Requires surgical implantation of beacons
  - Cannot be used with metallic prosthesis
  - Cannot be used with implanted electronic medical device

Optical Tracking

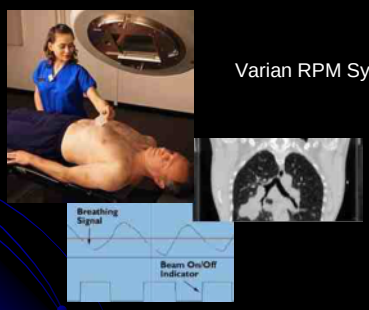
- Uses fiducials with reflective surfaces
- Fiducial location relative to target isocenter is known.
- Fiducial location tracked in realtime using cameras in room so that target isocenter location relative to machine isocenter is calculated.

Optical Tracking System



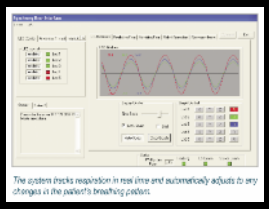
T. Wagner, S. Meeks, F. Bova, W. Friedman, T. Willoughby, P. Kupelian, W. Tome, *Optical Tracking Technology in Stereotactic Radiation Therapy.* Medical Dosimetry, 32(2): 111-120, 2007

Optical Tracking - Gating



Varian RPM System

Optical Tracking - Gating



http://www.accuray.com/a/pdf/Synchrony_Sellsheet.pdf

Beam Tracking

Accuray Inc

Optical Tracking

- Application
  - Any Region of the body
- Resolution
  - Sub-millimeter
- Pros
  - Independent system that can be retrofitted to existing facilities (dedicated for the Accuray system)
- Cons
  - Correlation of external markers and tumor needs to be established

Video tracking

- Reference video images taken after physician has approved setup on first day
- On subsequent days, a video camera grabs images of the patient setup and live image subtraction occurs to give therapists realtime feedback on patient positioning discrepancy
- Treatment can be interrupted and patient repositioned if large movement is noticed

Video Tracking

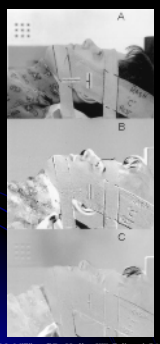


Fig. 2. Clinical use of a video-based patient positioning procedure begins with the acquisition of a pair of reference images (A), acquired on the first day of treatment after a physician has approved portal images of the setup. On all other treatment days, the reference images are retrieved from the image archive and subtracted in real-time from live video (B). With the aid of a computer monitor in the treatment room, therapists use the live subtraction images to interactively return the patient to the initial position (C).

Johnson LS, Milliken BD, Hadley SW, Pelizzari CA, Haraf DJ, Chen GT, *Initial clinical experience with a video-based patient positioning system.* Int J Radiat Oncol Biol Phys. 1999 Aug 1;45(1):205-13.

Video Tracking

- Application
  - Any Region of the body
- Resolution
  - Millimeter
- Pros
  - Independent system that can be retrofitted to existing facilities
- Cons
  - Does not consider internal motions that are not reflected externally

Closing Comments

- Pre treatment and on treatment imaging is critical to the success of radiation therapy
- Management of interfraction (between Tx) and intrafraction (during Tx) motion
- Imaging for Treatment delivery typically starts at the time of patient simulation
- The strengths and limitations of each of the many options that are becoming available need to be understood and the appropriate method should be applied for the appropriate task
- Integration of the imaging and delivery components is critical in this continuously evolving clinical application

The University of Texas Medical School at San Antonio

CTRC Cancer Therapy & Research Center

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