Learning objective

The objective of this educational session is to review KV-CBCT and MV-CBCT imaging systems for daily localization.

Outline

1. Commissioning, image quality, dose, registration process, and acquisition modes
2. Clinical integration
3. QA, stability over time, and downtime
4. Standard clinical applications
5. Novel clinical applications
6. Technology evolution and future directions

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Why CBCT?

- Advances in treatment planning and delivery systems allow for higher doses to target and lower dose to normal tissue.
- With the resulting steep dose gradients, motion management (inter and intra-fraction) becomes more critical.
- Tumors often not visible in 2D images.
- Role of CBCT is to help reduce interfractional motion and try to assess patient status (tumor evaluation, adaptive planning, ..)

Analysis of IGRT Studies

- Performance of various IGRT correction methods in the prostate.
- Residual error indicates the remaining deviation after correction of the prostate centroid from its planned position.
- Not all prostate localization methods are considered here (in-room CT, MV CT, optical guidance, implanted electromagnetic fiducials).

KV CBCT

Retractable X-ray tubes and amorphous silicon detectors
Mounted at 90 degree from the treatment room beam CAX
Acquiring projections (full, half, partial-rotation) around the patient to construct 3D or 4D information
Acquisition time ~ 1 min
Reconstruction time

Modes of Acquisition
**Problem with CBCT??**

- Large quantity of scattered radiation in the patient reaching the detector
- Scatter reduces contrast and contributes additional noise and induces localized artifacts
- Scattering within the patient can contribute additional dose to the patient

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To improve the image quality of kV CBCT the following modifications could be made except:

| 20% | 1. utilizing compensating filters with large modulation factors |
| 20% | 2. scatter correction algorithms |
| 20% | 3. adjusting the air gap between the patient and the detector |
| 20% | 4. reducing the longitudinal FOV |
| 20% | 5. utilizing grids |

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*answer is (1)*

Ref:
Patient Dose from CBCT

- System Dependent
  - kV/ mA
  - Number of projections
  - kV system properties (bow-tie)
  - kV system field size
- Patient Dependent
  - Size/shape of patient
  - Body part
- What is our interest?
  - risk/ benefit ratio needs to be considered

CBCT Dose

- Dose were measured using phantom and in-vivo TLDs for prostate patients
- AP skin doses ranged from 3-6 Gy for 20-23 separation
- The Lt skin dose was ~4.0 Gy while Rt skin was ~2.6 Gy (due to gantry rotation)
- Central dose was ~3.0 Gy
- The left hip received 10-11 Gy while the right received 6-7 Gy

CBCT Dose Reduction

Dose reduction can be accomplished by the reducing the exposure (mA, mS) → image quality
The aim is to improve the low dose image quality by reducing noise in the sinogram before image reconstruction
(A) 10 mAs
(B) 10 mAs with noise reduction algorithm
(C) 80 mAs
Experimental results indicate the possibility to reduce the CBCT dose by a factor of 1.8 without loss of useful information

The management of imaging dose during image-guided radiotherapy:
Report of the AAPM task group 75 (Murphy et. al.)
Keeping the other factors the same, patient dose (central mean dose) from KV CBCT will be increased with:

| 20% | 1. decreasing the kV/mAs settings |
| 20% | 2. scanning thinner patients |
| 20% | 3. decreasing the number of projections |
| 20% | 4. using smaller FOV or field size |
| 20% | 5. using compensating filters |

answer is (2)

Refs:

Clinical Protocol for Prostate Cancer

Data Preparation
- Planning CT with structure set
- Isocenter information
- Send via Record Verify System, local load...

Workflow
- Select patient
- Extend arm/entry starting point
- Imaging parameters
- Acquire/reconstruct CBCT
- Align bony, soft tissue, VOI
- Apply shifts and record
- Post shifts
- Treat

Tolerated difference between the planning CT and CBCT depends on image quality, image registration, internal organ motion, margin definitions, user experience which are clinic and anatomic site dependent.
HU Verification

- The differences in HU values between CT and CBCT for the Capphan were less than 10 HU for most disks materials.
- The profiles of CBCT showed lower HU at the periphery (50 to 200 HU).
- CBCT HU from patient data showed lower HU than CT.
- The dosimetric consequences (MU/Gy, isodose curves, DVH) were within 2-3%.
- 105% isodose cloud was larger for CBCT lung.
- Areas enclosed within the 90% matched very well.

Table 1: Comparison of HU in different views of patients.

<table>
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<th>Bone</th>
<th>CPH</th>
<th>CPNS</th>
<th>Panel A</th>
<th>Panel B</th>
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<td>87.4</td>
<td>Panel A</td>
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<tr>
<td>Large case</td>
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<tr>
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CBCT Brain Maxillary

- Reference CT maybe different from CBCT (organ deformation).
- Modified CBCT images (mCBCT).
- Dose computed based on the mCBCT was used as a surrogate in the evaluation of CBCT-based dose calculation.
- mCBCT possesses the geometric information of the CBCT yet the e-density distribution mapped from the reference CT.
- Correspondence between reference CT and CBCT was accomplished utilizing Biplane deformable image registration software.
To examine the dosimetric impact of margin reduction from 10/6 to 5/3 for prostate patients undergoing daily CBCT
• Use plan from Reference CT overlaid onto CBCT
• Quantify residual error after 3D image registration

QA Program
• Safety
• Geometric accuracy (isocenter, accuracy of shifts)
• Image Quality
• Software/data management

Geometric Calibration
5 isocenters to characterize
1. Mechanical isocenter
2. Radiation isocenter
3. Imaging isocenter

Portal images and CBCT images of ball-bearing (BB) mounted on micrometric stage
Location of the BB is detected from each projection and the apparent trajectory of the BB in the U V directions is plotted against gantry angle
Flexmap describing the discrepancy between the mechanical isocenter and the volumetric imaging system and the radiation isocenter (corrected reconstructed software, compensated by servos in the robotic arms)
OBI: Daily QA

Daily QA procedure checks the geometric accuracy of the OBI system by performing the following tests:

**Test 1: Tube/detector positioning accuracy**
Assures that the imagers (MV, S&K, and K) isocenter matches the LINAC isocenter.

**Test 2: Matching and couch motion accuracy**
Positional differences detected by the OBI workstation can be reliably transferred to couch motion.

Safety QA

- Interlocks (motion disabled)
- Door interlocks
- Tube warm up

Annual CBCT QA

- Mechanical checks (geometric calibration)
- Imaging dose (mA, HVL, ...)
- Image quality
  - Scaling/distance (0.5 mm tolerance)
  - CT number uniformity-baseline established
  - Spatial resolution-baseline
  - Low contrast resolution-baseline

Which of the following tests you would consider the least performed on monthly basis for On-Board Imaging QA procedure:

- 20% 1. safety
- 20% 2. imaging dose
- 20% 3. geometric accuracy
- 20% 4. image quality
- 20% 5. data storage capacity
Which of the following tests you would consider the least performed on monthly basis for On-Board Imaging QA procedure:

1. safety
2. imaging dose
3. geometric accuracy
4. image quality
5. data storage capacity

Answer is (2)

Ref:

Summary

- Scatter is the major issue in CBCT image quality
- Many commercial products have been introduced improving the image quality of CBCT
- Imaging dose: decreasing the exposure, number of projections, filters, algorithms
- Though dose calculated on CBCT agree with reference CT dose for some clinical sites (prostate), it is not recommended to replace the conventional CT with CBCT (inferior image quality to delineate tumor and critical structure, limited FOV)
- Several publications addressed QA guidelines.

Thank you