Dosimetry of double orbit cone beam computed tomography (CT) as applied to image guided radiotherapy (IGRT)

Ariel Jefferson, Dandan Zheng
Department of Radiation Oncology
Division of Medical Physics
VCU Medical Center
IGRT: current status

- Varian Trilogy linear accelerator with integrated on-board imager
- Efficient imaging systems allow for precise delivery of radiation treatment
- On Board Cone Beam CT is a relatively new development in image guided radiotherapy
**Cone beam CT (CBCT)**

- Pulses of low energy kV x-rays
- 2D projections → reconstruct in 3D
- Complete axial coverage and ~14 cm longitudinal coverage
Double orbit imaging proposal

- Objective: extend the longitudinal coverage of our CBCT images by implementing a protocol involving multiple scans in series.
Double orbit procedure

- Step and shoot modality
- Standard protocol: scan superior to inferior
- Abut region: 1.5 cm wide
  - Essential for 3D to 3D image registration
  - Corrects for patient movement
Previous double orbit results

Head and neck patient; single orbit (~14 cm)  Head and neck patient; double orbit (~27 cm)
How does this new imaging technique affect the patient?

- Additional absorbed radiation dose
  - We want to obtain a geometric profile of the dose distribution at the center and at the periphery
- CTDI: computed tomography dose index
  - Acrylic material is analogous to the human body
- Thermoluminescent dosimeters
Thermoluminescent dosimeters (TLD)

- **LiF TLD chips**
  - 1/8 inch square by 30/1000 inch depth

- Each chip measures the absorbed radiation for a single point
  - Radiation causes chemical reaction
  - Latent measurement tool

**Irradiation**
- Incident radiation
- Conduction band (unstable)
- Electron trap (latency)
- Valence band (stable)

**Measurement**
- Conduction band (unstable)
- Electron trap
- Valence band (stable)
Preliminary tests

- **Limitations**
  - Their response is energy dependent
  - Non-uniformity of individual chips

- **Certain characteristics of our TLD batch were assessed before acquiring data**
  - Uniformity of response
  - Linearity of response to dose
  - Reproducibility - does each TLD respond to radiation consistently?
TLD processing steps

1. Annealing
   Heat at 400° C for 1 hr, then 100° C for 2 hr
   Purpose of annealing: Set to zero

2. Irradiation

3. Readout
   TLD responses are read and recorded individually

Harshaw 3500 TLD reader
Preliminary assessments

- The standard deviation (uniformity) of the TL readings decreased with increased dose
  - Due to the deposition of more photons
  - More photons = higher TL readout
- Our batch showed sufficient linearity in response and reproducibility

Comparison of absolute TL readings variation for different dose and energy

- High dose, high energy
- High dose, low energy
- Low dose, high energy
Relating the TL reading to absolute absorbed dose

- The absolute dosimetry of TLDs is not apparent
- Readout in nano-Coulombs
- Convert the nC to absolute dose unit

Harshaw 3500 TLD reader
Ion chamber (IC) calibration

- Place ion chamber inside a disk shaped water phantom (analogous to CTDI acrylic); 5 TLDs set adjacent to the IC
- Perform one double CBCT scan
- Connect ion chamber to electrometer (outputs a reading)
Absolute dose calculation

- AAPM (American Association of Physicists in Medicine) protocol for absolute dose calculation from in-water ion chamber readings (M)

\[ D_w = MN_k P_{qcham} P_{sheath} \]

- Dose to water is calculated in Gy
- \( D_w = 10.29 \text{ cGy} \) for one double CBCT
TLD calibration

- Avg TL readout: 51.94 nC
- Calibration factor:
  - \( 51.94 \text{ nC} \approx 10.29 \text{ cGy} \) absolute dose
Head and neck patient simulation

Sensitive area is increased by placing the two phantoms in series; allows for complete coverage of a double CBCT
Custom modifications

- Three custom holders designed to harbor TLDs
  - 33cm (CAX)
  - 15 cm
  - 16 cm
Setup

- After annealing, two TLDs were placed in each well of the holders
- Holder placement:
  - Long 33 cm holder: central axis
  - 16 cm holder: peripheral channel head phantom
  - 15 cm holder: peripheral channel body phantom
Double Cone beam CT acquisition

- Beam isocenter (first scan): 12 cm from the sup. axial surface
  - Beam length: 13.8 cm (6.9 cm on either side of the isocenter)
  - Isocenter placement accounts for beam scatter

- Second CBCT scan: shift the patient
  - Clinical procedure: 12.3 cm shift

- 4 double cone beam CT scans were performed
  - 8 scans total
Conclusions

The overlap in the abut region causes a marked increase in the absorbed dose

- Is the extra dose warranted?

- Next step: Investigate methods of lowering the resulting absorbed dose while maintaining the integrity of our images
  - Develop better image registration techniques
  - Experiment with lowering the current-time (mA·s) product through the x-ray tube
Acknowledgements

- Dr. Jeffrey Williamson
- Dandan Zheng
- Dr. Jun Lu
- The entire Department of Radiation Oncology and Division of Medical Physics
- Jeff Elhai and all of BBSI
- NSF and NIH


C. Yu, G. Luxton. TLD dose measurement: A simplified accurate technique for the dose range from 0.5 cGy to 1000 cGy. *Medical Physics*. June 1999


William Y. Song, Srjit Kamath, Shuichi Ozawa, Shiomi Al Ani, Alexel Chvetsov, Niranjan Bhandare, Jatinder R. Palta, Chihray Liu, and Jonathan G. Li. A dose comparison study between XVI® and OBI®