Improving treatment safety and quality through real-time Surface Guided Radiation Therapy (SGRT)

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Northside Hospital Cancer Institute (NHCI)

Radiation Oncology Program:

- 4 treatment clinics:
  - Atlanta
  - Alpharetta
  - Forsyth
  - Cherokee
- 10 Varian LINACs (incl. 3 TrueBeams)
- 4 AlignRT systems (SRS module, MMI)
- Gamma Knife Perfexion
- 3 HDR suites (Varian and Elekta)
- LDR program
The original Toy Story (1994) utilized the Polhemus 3 Space Digitizer (a 3D scanning laser wand) to convert clay models into computerized 3D surface matrices – then mathematical techniques transform these subdivision surfaces into tens of thousands of possible positions and expressions.
Between 2001 (LOTR: Fellowship...) to 2016 (Jungle Book), Weta Digital won six Academy Awards for Best Visual Effects. Among other techniques, their computer graphics modeling programs transform living people from motion-capture acting into fantastic creatures – like Andy Serkis into Gollum and King Kong.
With the Microsoft Kinect system, an IR laser passes through a diffraction grid to create an expanse of projected IR dots. The software program knows the projected pattern as well as other geometric parameters of the system, and thereby mathematically reconstructs the surface contour.
### Surface-Guided Radiotherapy (SGRT)

#### Different terminologies for similar technology:

- Photogrammetry (see AAPM TG 147¹)
- Optical Surface Monitoring
- Optical Localization
- Surface Map Imaging
- Video-Based Motion Management²
- Surface-Guided Radiotherapy

Surface-Guided Radiotherapy (SGRT)

Real-time, non-radiographic localization and positioning via optical or infrared tracking of an external surface contour.

- Moving beyond CCTV-monitoring of the patient to quantitatively track patient position and motion to mm or even sub-mm accuracy
- Refresh rate close enough to real-time monitoring of patient movement
- No additional ionizing radiation dose to the patient
Surface-Guided Radiotherapy (SGRT)

**Motivation:**
- Reduce *interfraction* positional variation
- Mitigate *intrafraction* motion, like respiratory motion or small but significant movements in stereotactic settings
- Allow for precise geometric reproducibility in special treatment setups, as in deep-inspiration breath hold
- Facilitate faster setups and treatments
SGRT at NHCI

NHCI primary reasons for seeking an SGRT solution:

1. Accurate, reliable means of DIBH for left-breast patients
2. Real-time monitoring system with sub-millimeter accuracy for frameless (mask-based) LINAC SRS/SRT
3. Improved setup times and reproducibility, especially for difficult anatomies, with less radiographic imaging
Surface-Guided Radiotherapy (SGRT)
Surface-Guided Radiotherapy (SGRT)
SGRT at NHCI

- Three camera-projector pods project a pseudo-random optical pattern on the patient
- Software creates a real-time patient surface contour

Image courtesy of Vision RT Ltd.
SGRT at NHCI

- 3D surface imaging provides **real time, 6DOF feedback** during the patient setup process and throughout the treatment delivery.
With the Motion Management Interface (MMI) activated, **beam is held automatically** when patient motion exceeds preset tolerances.
SGRT at NHCI

Since 2014, we have treated hundreds of patients with AlignRT, and several conclusions have been cemented for us through both positive and negative experience.

1. Patients move much more frequently and with greater magnitude than we ever realized

2. Camera-based SGRT has the potential for exceptional geometric accuracy in the real clinical setting

3. The carefully-chosen surface region of interest is an excellent surrogate for internal anatomy…except for when it’s not
For privacy reasons, the following learning incidents are presented anecdotally and anonymously, without indication of where or when they may have occurred or been reported.
Learning Incident #1

SBRT (lung) immobilization incident:
- Patient immobilized via Vac-Lok and wingboard, but adjusted his arm position slightly after CBCT to ease shoulder pain
- No discernible movement on video monitoring
- SGRT system indicated a longitudinal shift out of tolerance (>2 mm): no beam allowed by MMI
- One therapist suggested capturing a new reference to allow beam on
- Repeat CBCT revealed an 6 mm longitudinal shift
Learning Incident #1

Lessons learned:

- All members of the treatment team, from simulation through delivery, must be adequately trained
  - Trained in “what if” scenarios
  - Use the system on large-margin cases first

- No discernible movement on video monitoring does not mean that no movement has occurred
  - Trust your well-commissioned system when it says something is wrong

*Including temp workers and pinch hitters! Other reported incidents due to lack of training: a) DIBH where a new therapist was adjusting the couch vertical between free-breathe setup and breath-hold verification; b) dosimetrist who sent surface contour from original plan instead of replan, even though the isocenter changed, because “it’s the same patient”

**Physicists deal with this routinely: if a QA test fails, take the time to analyze the cause of the anomaly, rather than assuming everything is fine and the test itself is off.
Learning Incident #1

“It is important to note that pretreatment image guidance offered by some systems, allows correction only at specific time points during the patient alignment process, and in general is not continuous.”

AAPM TG-147

Therapists: all the time and effort you spend accurately setting up the patient and carefully employing IGRT!
Dosimetrists: all the time and effort you spend intricately shaping your dose gradients to both cover and protect!
Learning Incident #2

SRT couch rotation incident:
- Patient immobilized via thermoplastic mask and customizable head/neck rest
Learning Incident #2
Learning Incident #2

The Head Plate

The Main Plate

The Adjustment Mechanism

Image courtesy of Vision RT Ltd.
Learning Incident #2

SRT couch rotation incident:
- Patient immobilized via thermoplastic mask and customizable head/neck rest
- Plan involved two large couch rotations, and AlignRT “drifted” out of tolerance at these extreme positions
- Immediate solution was to return to zero and CBCT before rotating and immediately treating each arc
- Further investigation revealed that the SGRT system had not been calibrated in a number of months (due to miscommunication)

*QA system involves daily plate verification, monthly plate “calibration” with visual setup (which really only verifies that the monthly calibration image is still good), and radiographic cube calibration which aligns imaging isocenter with SGRT isocenter. Neither daily nor monthly QA tests involve couch rotations, which may be the first to show “drifting” results if the relative positions of the camera pods change over time.
Learning Incident #2

Lessons learned:

- The geometric accuracy of the SGRT system is only as good as your routine LINAC/SGRT QA program

- SGRT is not a substitute for IGRT – particularly in the stereotactic setting (more on this next)
Learning Incident #3

“Incidents” actually - a general observation:

- One might speculate that if the SGRT system can potentially localize the surface contour with sub-millimeter accuracy, why can’t we by-pass imaging?
- In some cases we might: for example, DIBH.
- HOWEVER, the external surface contour – as much of an improvement as it is over artificial surrogates – is still just that: a very complicated surrogate.
- SGRT allows highly accurate monitoring of patient positioning but is not a substitute for IGRT
Learning Incident #3

“Systems based on video or radiofrequency technology typically have a fast update rate and therefore can be used to track intrafraction changes. Depending on disease location and individual patient motion characteristics, surface tracking technologies may or may not provide a good surrogate for internal motion; surface tracking has been shown to be a poor surrogate for prostate motion and may or may not have an adequate correlation with targets in the thorax and abdomen, depending on individual patient characteristics.”

Learning Incident #4

SBRT (lung) RapidArc occlusion incident:

- During treatment delivery with RapidArc, the SGRT system began giving erratic and unusable feedback
- Assumed there was a computer or software error – but it misbehaved uniquely for this patient multiple times
- Went back to the basics: *paid careful attention while capturing reference and defining region of interest*
- Subsequent fractions proceeded without the SGRT data anomalies
Learning Incident #4

Lessons learned:

- **Follow the setup and treatment preparation steps carefully and in sequence, including:**
  - Attention to room lighting and shadowing
  - Software set to an appropriate skin tone
  - Region of interest selected carefully, without clothing, immobilization devices, uniqueness of anatomy, etc.
  - Reference image capture without camera blockage (gantry, OBI, patient anatomy, etc.)
  - QA performed in similar room lighting to treatment
Learning Incident #5

Palliative incorrect isocenter incident:

- Palliative setting for treatment of bone metastases: two isocenters
- Therapist A setup the patient and the SGRT system to isocenter 1
- Therapist B moded up the LINAC to isocenter 2
- Patient received one treatment off-center pelvic fields at the thoracic spine isocenter
Learning Incident #5

Lessons learned:

- Many stars (mis)aligned to allow this mistreatment:
  - General miscommunication
  - Failed timeout procedure
  - Inappropriate override of the treatment couch parameters
  - Lack of awareness of treatment fields during setup
- Overreliance on any one system without maintaining a firm grasp of basic principles is a recipe for disaster!
Successful SGRT: what’s required?

- Physician(s) aware of the appropriate application of SGRT techniques (including limitations of the technology and patient)
- Dosimetrist trained in the process flow for transferring plan data
- Therapists aware of their role in QA, implementation of SGRT, and limitations of SGRT
- Physicists who carefully perform LINAC/SGRT QA and participate in treatment with scrutinizing care
- Every member of the treatment team maintaining firm grasp of basic principles, including QA, simulation, treatment planning, and treatment delivery