Adaptive Replan Using on Treatment Cone Beam CT for Deformation of Original CT Simulation

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Outline

- Case Study: Palliative Head and Neck Patient that needs Replanning
- Possible ART Tools
  - Planning on CBCT
    - Background
    - Previous studies
    - Pros and cons
  - Deforming planning CT to CBCT to replan
    - Background
    - Previous studies
    - Pros and cons
- Approach we took/tools that we used
  - Varian Halcyon 2.0
- Future Considerations
Clinical Problem

- A 65-year-old male, after presenting to the emergency department, was diagnosed with (T0N3M0) squamous cell carcinoma of an unknown primary with a large fungating right neck mass.
- The patient was experiencing severe pain and pressure sensation in the neck with decreased range of motion, as well as loss of appetite and decreased energy. The patient was only able to tolerate some liquids orally and a feeding tube was placed.
- Palliative radiation therapy of 250 cGy x 20 fractions was recommended to help improve his symptoms.
- For patient setup, a CBCT was performed prior to every fraction, aligning to boney anatomy.

Clinical Problem

- Over the course of several fractions, tumor shrinkage was observed on the CBCT, and after 10 fractions of treatment a decision was made to replan.
- The patient was unable to attend a planning CT scan without ambulance transport.
- Patient was treated on Varian Halcyon.
Clinical Problem

- Patient anatomy has deviated significantly from planning anatomy
  - Usually perform another CT simulation & replan
- Need an accurate representation of patient anatomy and the electron densities to model how the dose will be deposited
- Need to Adapt!

Adaptive Planning?

![Diagram of Adaptive Planning Process]
Clinical Solutions?

• For patient setup, a CBCT was performed prior to every fraction, aligning to boney anatomy!
• Halcyon CBCT’s look pretty good!
• Would strongly prefer if patient didn’t have to get another CT

Potential options

1. Plan on CBCT
2. Deform planning CT to CBCT for treatment planning
3. Rescan and Replan
Potential options

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1. Planning on CBCT
   - Why not use the CBCT?
   - CBCT has not been validated for treatment planning.
   - Major issue with CBCT is scatter
Cone Beam vs Fan Beam

- Excellent for IGRT/boney anatomy matching
- But Image quality is not as good
- Decreased number of projections
- Lots of scatter!

Can we reduce scatter?
- Bow tie filter
- Imaging grate
- Scatter deconvolution
- X ray fluence modulation

Cone Beam vs Fan Beam

- CBCT More Scatter
  - More noise, less soft tissue contrast
  - More artifacts
Fan vs Cone Beam

- Need to convert the Hounsfield Units to electron density in order to calculate dose

\[ HU = 1000 \times \frac{\mu - \mu_{\text{water}}}{\mu_{\text{water}} - \mu_{\text{air}}} \]

How bad is CBCT?

- 10% difference between a 18 cm and 40 cm diameter phantom
- Phantom used for calibration should be close in size to patient.
- Streaking artifact can give values distorted by several hundred HU
- 8% difference in electron density results in 1% change in dose calculation
- Conclusions:
  - Phantom size for HU calibration must resemble patient. Important for larger patients
  - Scan length important

Replanning Studies

- Used CatPhan phantom to assess difference in HU between Fan and cone beam
- Differences in HU near edge of phantom
- Difference in 100 HU when using half fan and full fan.
- Impact on the dose is insignificant

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Replanning Studies

- Study done with head and neck, prostate patients
- Good dose agreement for both prostate and head and neck
- Head and neck
  - Scan length is 14 cm
  - Must do 2 scans and stitch them together
- Hard to delineate change in tumor.

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Treatment Planning on CBCT

- Dosimetry agreement of ~ 3-5%
- HU calibration curve depends on size on phantom
- Artifacts can cause problems
- Scan length causes significant issues
- Poor soft tissue contrast, hard to delineate tumor

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Ding et al. at Radiotherapy and Oncology 2007

Treatment Planning on CBCT

- Used for Palliative treatments with simple plans
- Various imaging systems tested

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Held et al. at Journal of Appl Clin Med Phys 2015
Treatment Planning on CBCT

- With CBCT calibrated correctly can get dose within ~3%
- Low soft tissue contrast, unable to delineate target
- Short scan length, may not include full treatment region
- Need to be careful when calibrating HU curve
  - Phantom size is important

Potential options

1. Plan on CBCT
2. Deform planning CT to CBCT for treatment planning
3. Rescan and Replan
Deform planning CT to CBCT for treatment planning

- Use DIR to map planning CT HU to anatomy in CBCT
- Have to worry less about
  - HU calibration curve
  - CBCT artifacts
  - Limited field of view
- Contours move with image deformation

Background for DIR

- Overall Goals
  - Match one point on an image to another point on an image.
  - Find the transformation map that maps all points
Background for DIR

- Uses
  - Auto-segmentation
  - Contour propagation
  - Dose mapping and Accumulation
  - Organ Evolution

Deformable Image Registration

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AAPM Task Group 132
Image Registration

- Adjust apply transformation to image A to get image B
  - Adjust different parameters

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Image Registration

- What Parameters can we adjust?
- Affine Transformations
Rigid Registration

- Apply translations and rotations

Deformable Image Registration

- Transformation Model
  - Non affine Transformation:

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Deformable Image Registration

- Transformation Model
  - Non affine Transformations

1D example B Splines
- Basis functions weighted by different amounts
- Each peak moves a region or even a voxel
- Transformation can be very local
- Can change the blue without changing the green
Deformable Image Registration

- Sum of basis function gives a curve to calculate how much to move voxels
- Deformation vector at each vector
- Usually start coarse then zoom in to finer resolution
- People are not B splines

Deformable Image Registration

- Rigid registration perform geometric transformation, similarity metric can be your eyes
- For deformable registration need the computer to do some work
Deformable Image Registration

- Similarity Metrics
- Intensity Based
  - Sum of square differences
  - Cross correlation
  - Mutual information
- Geometric Based
  - Point matching
  - Line/edge matching
  - Surface matching

\[ SSD = \frac{1}{N} \sum [I_F(x) - I_M(x)] \]
DIR Use

- Assumption: For two images being registered, every point of one image corresponds to one point on the other image
- Not strictly valid for:
  - Change is rectum bladder filling
  - Air cavities
  - Tumor shrinkage
  - Swelling and Edema
  - Weight loss

Deformable Image Registration

- DIR algorithms can vary widely
  - Different transformation methods, similarity metrics, optimization methods
Head and Neck Studies

- Compare clinician draw contours with Deformed contours
- Clinicians rated contours
  - OARs no or minor modifications required
  - Targets need to be thoroughly reviewed

Hardcastle et al Radiation Oncology 2012

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Head and Neck Studies

- Compare dose on deformed planning CT to dose on replan CT
- Found doses comparable to doses calculated on replan CT
- Approach limited by the field of view and low soft tissue contrast

Veiga et al Medical Physics 2014
General Studies

- Studies with prostate treatments
- Deformable approach more reliable than calculation on CBCT
  - 0.1% mean dose difference between deformed planning CT and replan
- Registration can be affected by artifacts
- Calibrating CBCT helps registration

Deform planning CT to CBCT for treatment planning

**Pros**
- No need to perform separate HU calibration
- OAR contours are deformed

**Cons**
- Artifacts can cause problems in deformation
- Target contour needs to be reviewed
- Deformation at the edge of CBCT will not be registered
Time to Decide

1. Plan on CBCT
2. Deform planning CT to CBCT for treatment planning
3. Rescan and Replan

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Treatment
- 6 MV FFF Beam
- 800 MU/min
- RapidArc (2 RPM)
- IMRT (4 RPM)
- 100 cm bore
- No 6 DOF couch

Imaging
- Required
- MV planar/CBCT
- kV CBCT
- Large FOV
- 7-15 seconds

MLC
- Dual-layered
- 1 cm width leaves
- 5 mm resolution
- 28x28 cm field (1 iso)
- 28x36 cm field (2 iso)
- 100% overtravel
- 5 cm/sec speed
Extended Field of View

Iterative Cone Beam Reconstruction

- Uses Acuros CTS algorithm
  - Uses current reconstruction on TrueBeam as a first pass
  - Models primary and scatter contribution of patient remove scatter contribution
  - Perform second pass reconstruction
Iterative Cone Beam Reconstruction

- Improvements in image noise, image intensity homogeneity and boundary sharpness
- Soft tissue contrast improved for delineation of prostate and parotid glands

Gardner et al Advances in Radiation oncology 2018

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Iterative Cone Beam Reconstruction

- Artifacts due to photon starvation and streaking improved
- Enhances low contrast detection while maintaining spatial resolution
- Reconstruction takes additional 10-30 sec

Mao et al Technology in Cancer Research and Treatment 2019

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Halcyon 2.0

- Extended field of view
- Less artifact
- Better soft tissue contrast
- Faster imaging times

HU Calibration using iCBCT

Electron Density Table

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Deformable Registration

- Initially perform rigid registration
- Intensity based registration to minimize intensity differences between images
- Multi resolution approach
  - Starts very coarse and then refined to higher resolution
- Optimization modified gradient descent
- Reg refine
  - User can assess/adjust registration in different regions
  - Iteratively used to improve DIR

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Deformable Registration

- Deformable registration was performed
- Physician reviewed contours
- RapidPlan head and neck model was used to generate plan
- Replan was treated for last 10 fractions
- PTV mean/max was reduced
- OAR doses reduced

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Clinical Problem Status

- Treated palliative Head and neck case for 20 fractions
- Significant tumor shrinkage seen and replan was made at fraction 10
- Excellent response
- One month follow-up patient reported being pain free and had normal range of motion
The Future

- Approached was used for a palliative case that was not able to get a re-CT without ambulance
- Physics reviewed deformation
- Physician reviewed contours
- Need more validation for more complete implementation
Conclusions

- For treatment planning lesser quality CBCT images present challenges, extra considerations
  - Change in HU
  - Artifacts
  - Limited field of view
- Deformable registration from CBCT-CT also needs to be verified
  - Every deformable image registration is different, needs to be validated
- Improved CBCT technologies will help in this technology and will aid in developing ART

Acknowledgements

Todd Atwood, PhD
Andrew Sharabi, MD, PhD
Whitney Sumner, MD
Patricia Hua, CMD