Dose Calculation on MVCBCT Images Acquired for on-line Position Verification

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Educational Objectives

- Understand the requirements for dose re-calculation on (CB)CT images
- Know the various methods available for obtaining accurate dose calculations with MVCBCT images
- Appreciate the extent of clinical applications offered by dose re-calculation

Collaborators

Have also contributed to this presentation:

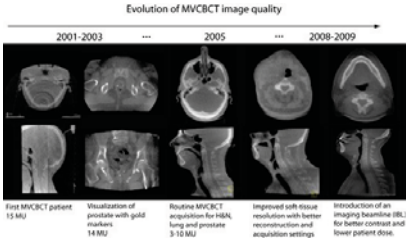
Minghui Lu
Weigang Hu
Pierre Graff-Cailleaud
Andrew Hwang

This work is supported in part by Siemens OCS

Presentation Layout

- Requirements for dose re-calculation
- Effects of image quality on dose calculation
  - Uniformity
  - Noise
  - CNR
  - Artifact (scatter, beam hardening, etc)
- Image correction methods
  - Dose calculation with MVCBCT:
    - H&N
    - Pelvic
    - Thorax & abdomen
    - in presence of high-Z material
    - Imaging Beam Line (IBL)
- Clinical applications
  - Planning in presence of high-Z material
  - Identify Z value of foreign objects
  - Dosimetric impact of anatomical changes
  - QA based on 3D delivered dose
  - ART/DGRT

Evolution of image quality



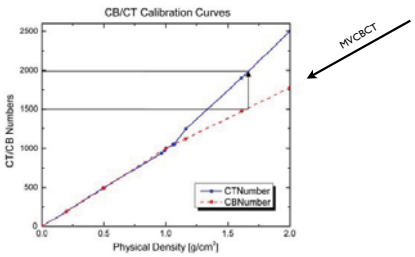
Requirements for dose re-calculation

- Stability of CT Number
  - Time
  - Target location (uniformity)
  - Patient size
  - Imaging dose
- Complete Anatomy
  - Longitudinal + lateral directions

Stability of CT Number

The stability of the beam output and detector reading ... was better than 2% at all exposure levels over a period of 12 months.

Morin et al., Med. Phys. 36(4), 1421-1432; 2009



Requirement for dose re-calculation

Physical Performance and Image Optimization of Megavoltage Cone-Beam CT
Morin O., Aubry J.F., Aubin M., Chen J., Descovich M., Hashemi A.L., and Pouliot J.,
Med. Phys. 36(4), 1421-1432; 2009.

	ARTISTE	ONCOR/PRIMUS
Detector Model	Perkin Elmer AG9, adjustable gain	Perkin Elmer AG9
Scintillator/thickness	Lanex Fast	Lanex Fast
Build-up plate/thickness	Yes	Yes
Beamline	6 MV TBL, 4 MV IBL	6 MV TBL
Possible Arc	Full rotation	270 to 110
Maximum transverse FOV	40 cm	27 cm
Flat panel lateral offset	9.1 cm	no
Cranio-caudal imaging length	27 cm	27 cm
Typical patient dose @ iso	0.7 X	X
Head and neck	~3.4 cGy	~4.5 cGy
Thorax	~5 cGy	~7 cGy
Pelvis	~5 cGy	~7 cGy
CNR on Emma Phantom	1.3 Y	Y
Uniformity	>98%	>95%
Time to reconstruct 512³	60 s	105 s
Software	Syngo RTT	Coherence RTT

Both the transverse and the cranio-caudal imaging lentgh are important to meet the requirement for dose calculation. It is rather frequent to have treatment volumes that are covering more then 15 cm

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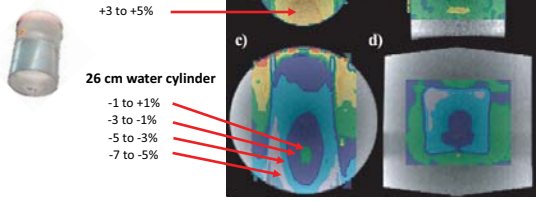
Dose calculation with cupping artifact

No correction



These images show that the dosimetric impact of large non-uniformities (~30%) result in errors that are much smaller than the non-uniformity itself. A good first order correction of the uniformity may be sufficient.

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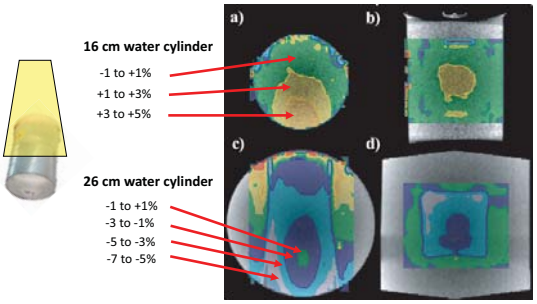

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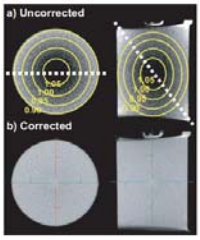
Cupping artifact correction approaches

Override CT# & assign bone and tissue density

2D: Correcting the projections
Monte Carlo models -> Thorax + Lung.
Experimental models

3D: Correcting the reconstructed image
Based on phantom measurements -> Pelvic
Based on reference CT image -> H&N
Based on histogram -> Spine, +



MVCBCT Image correction approaches

- Uniformity correction
  (Scatter, beam hardening, off-axis softening, etc.)
- Image-density calibration
- Missing data artifact correction
- Complementing missing data

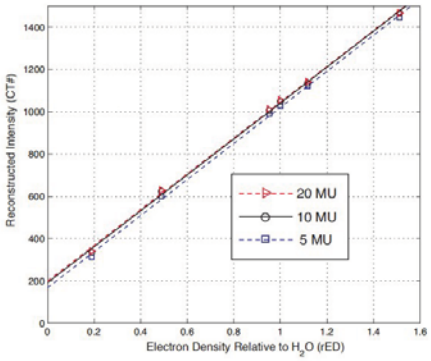
Dose Calculation using Megavoltage Cone-Beam CT
Morin O., Chen J., Gillis A., Aubin M., Aubry J.F., Bose S., Chen H., Descovich, M., Xia P. and Pouliot J., Int. J. Rad Oncol Biol. Phys. 67(4),1202-1210; 2007.

Correction of megavoltage cone-beam CT images for dose calculation in the head and neck region
Aubry J.F., Beaulieu L. and Pouliot J., Med. Phys. 35(3): 900-907; 2008.

Correction of Megavoltage Cone-beam CT Images of the Pelvic Region Based on Phantom Measurements for Dose Calculation Purposes
Aubry J.F., Cheung J., Gottschalk A., Morin O., Beaulieu L. and Pouliot J., J.Appl. Clin. Med. Phys. 10(1), 33-42; 2009.

Dose recalculation in megavoltage cone-beam CT for treatment evaluation: removal of cupping and truncation artefacts in scans of the thorax and abdomen
Petit S.F., van Elmpt W.J.C., Lambin P., and Dekker A.L., Radiother Oncol. 94: 359-366; 2010

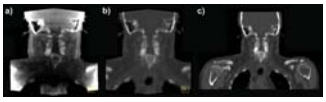
MVCBCT Image correction approaches

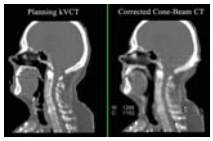


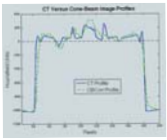
Electron density calibration of MVCBCT for different MU acquisitions.

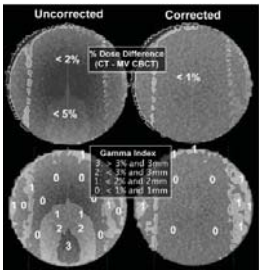
Dose calculation ... for H&N

based on phantom measurements







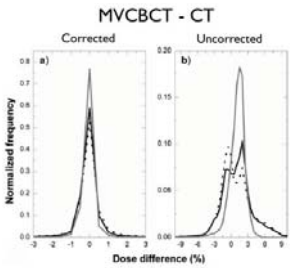


Dosimetric accuracy largely sufficient for clinical applications after image correction.

Int. J. Rad Oncol Biol. Phys. 67(4),1202-1210; 2007

Dose calculation ... for H&N

based on reference CT image



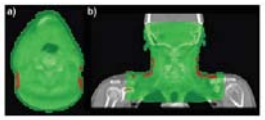


FIG. 8. Gamma index distribution for patient II, showing the spots where the index is >1 with the gamma function parameters set to 3%, 4 mm. (a) Axial slice, (b) Coronal slice.

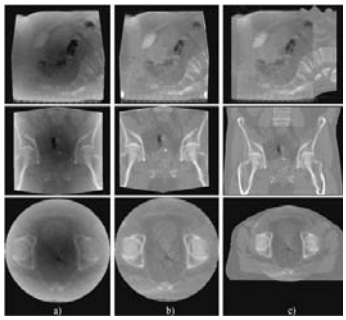
More than 95% of the volume is within 1% after correction.

Med. Phys. 35(3): 900-907; 2008.

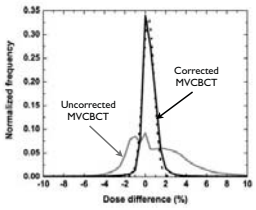
Dose calculation ... for pelvic

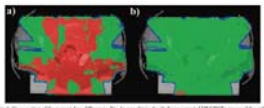
based on phantom measurements

For pelvis 95% of the volume is within 2%.



Images of a pelvic cone-beam (a) uncorrected (b) corrected and (c) completed using a kVCT image

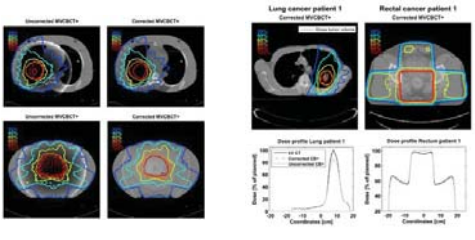


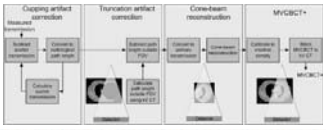


J.Appl.Clin.Med.Phys. 10(1), 33-42; 2009

Dose calculation ... for thorax & lung

based on Monte Carlo models

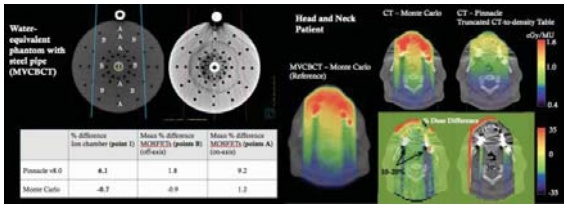




Dose recalculation in megavoltage cone-beam CT for treatment evaluation: Removal of cupping and truncation artefacts in scans of the thorax and abdomen

Steven F. Petit *, Wouter J.C. van Elmpt, Philippe Lambin, André L.A.J. Dekker
Radiotherapy and Oncology 94 (2010) 359–366

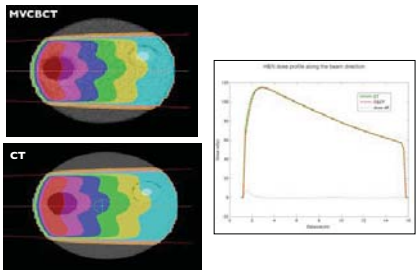
Dose calculation ... in presence of high-Z material



Metallic structures (i.e. gold crown or prosthesis) actually have CT number ~9000, which exceeds the maximum of 12-bit-scale CT number range. Although use of 14 bits could be an easy fix, some treatment planning systems are not capable of handling more bits per voxel. Another solution adapted for MVCBCT reconstruction and dose calculation mode in presence of metallic structures is to divide all intensity by 3 in the final CT images. For such cases, a separate HU-ED conversion table is generated.

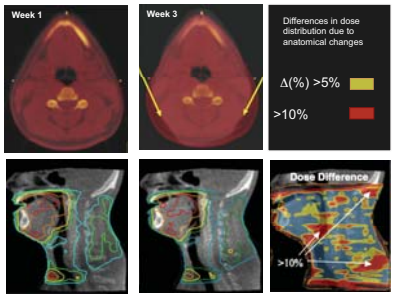
MVCBCT has fewer artifacts in patients with dental filling or hip prostheses.
A modified mapping method can be used to generate the MVCBCT images without saturating the CT numbers in high-Z material.
The unsaturated MVCBCT images can be used for accuracy Monte Carlo based or superposition convolution based dose calculation.

Dose calculation ... for the new Imaging Beam Line



Clinical Applications

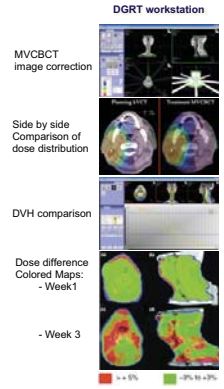
Dosimetric impact of anatomical changes



Integration of workflow

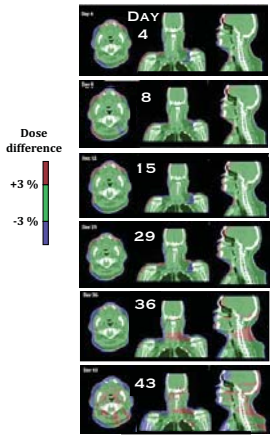
1. Import initial dose plan and MVCBCT image
2. Register the images as patient was treated
3. Correct and complement the MVCBCT image
4. Copy beams from planning CT to MVCBCT
5. Calculate treatment dose
6. Show DVH comparison and dose distributions
7. Display dose difference colored map
8. Use non rigid deformation to map dose grid
9. Accumulate dose

Int. J. Radiation Oncology Biol. Phys., Vol. 74, No. 2, pp. 583–592, 2009
PHYSICS CONTRIBUTION
DOSE RECALCULATION AND THE DOSE-GUIDED RADIATION THERAPY (DGRT) PROCESS USING MEGAVOLTAGE CONE-BEAM CT



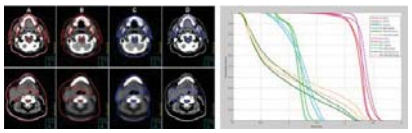
QA based on 3D delivered dose

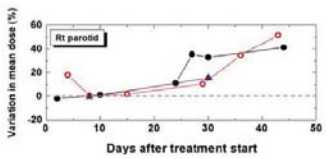
Dose difference colored maps for head-and-neck patients are made available every week for review of variations in delivered dose during treatment.



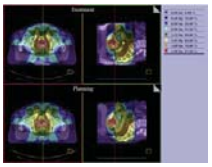
Dose delivered variations due to anatomical changes

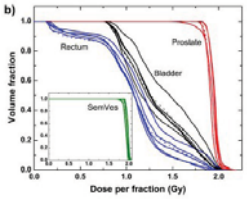
Head&Neck





Prostate





Dose Recalculation and the Dose-Guided Radiation Therapy (DGRT) Process Using Megavoltage Cone-Beam CT
Cheung J., Aubry J.F., Gottschalk A., Yom S., Celi J.C., and Pouliot J.., Int. J. Radiation Oncology Biol. Phys. 74(2): 583-592; 2009.

Summary

- Several methods exist to correct MVCBCT images -> clinical use
- Corrected MVCBCT can be used for accurate dose re-calculation
- Delivered dose recalculation allows:
  - Evaluate dosimetric impact of anatomical changes
  - An important QA
  - ART/DGRT

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