Potential Systematic Uncertainties in IGRT When FBCT Reference Images are used for Pancreatic Tumors

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Introduction

- Pancreatic cancer is the fourth most common cause of cancer death in US. Less than 5% of patients affected by pancreatic cancer survives 5 years after diagnosis.

- Radiotherapy of pancreatic cancer often applies a large planning margin in order to account for tumor motion and displacement.

- Applying a large planning margin increases the treatment toxicities of nearby critical organs, primarily the duodenum, small and large bowels, stomach, kidneys, and liver.

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Types of motion

- Interfractional motion
  - Setup changes
  - Patient anatomy changes (tumor shrinking, organ fill)
- Intrafractional motion
  - Respiratory motion
  - Patient motion during treatment
  - Anatomy changes

- To account for interfractional and intrafractional motions, margins are typically added to cover the CTV. Small margins can result in underdosing of the CTV, conversely, larger margins will lead to unnecessary dose to the adjacent normal structures

Image Guided Radiotherapy

- IGRT reduces ITV margins and setup uncertainties which decrease RT related toxicity and allow tumor dose escalation.

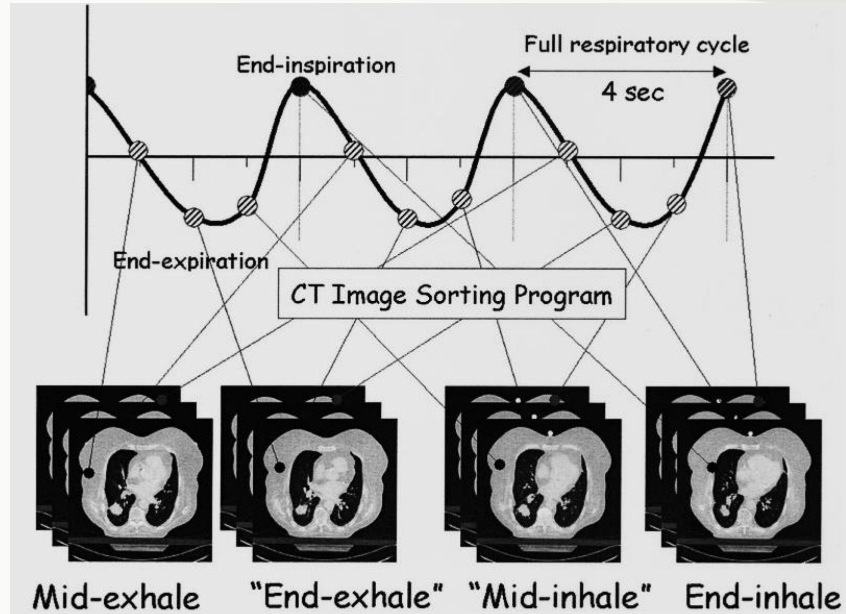
- IGRT techniques:
  - USG
  - Video Based: AlignRT
  - Planar x-ray: Room mounted or gantry mounted
  - CT
    - Fan Beam: Tomotherapy, In-room CT
    - Cone Beam: MV-CBCT, kV-CBCT
  - MRI
- Reference CT for IGRT:
  - FBCT: acquired in a short time
  - AIP: average intensity projection generated from 4D-CT

4D-CT

- The 4D-CT technique is based on a synchronization of the image acquisition and image reconstruction process with patients' breathing.

- Respiratory sensor: air bellows belts or optical tracking device.

- Two binning approaches:
  - PB (0-2π).
  - AB (breathing signal ful amplitude).
  - AB is more accurate than PB.



Rene' et al. Int. J. Radiation Oncology Biol. Phys., Vol. 60, No. 4, pp. 1283–1290, 2004

4D-CT

- The image quality depends on the reproducibility of the respiratory motion.

- The volume of images are 10 times so dose to the patient increase 3-4 times.

- Dosimetric accuracy using AIP and contouring accuracy using MIP generated from respiratory –correlated 4D-CT should be evaluated.

  - Han et al. compared AIP with FBCT for contouring organs at risk for lung SBRT and found no significant differences.

  - Tian et al. compared AIP and FBCT for planning and dose calculations for lung SBRT and concluded that the dosimetric characteristics are similar for both data sets.

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Han et al.. *Clin Oncol* 2010; 22:862-867.
Tian et al. *Med. Phys* 2012; 39:2754-2760.

Purpose

- To quantify the systematic uncertainties resulting from using free breathing computed tomography (FBCT) as a reference image for image guided radiation therapy (IGRT) for patients with pancreatic tumors.

- To quantify the associated dosimetric impact that resulted from using FBCT as reference for IGRT.

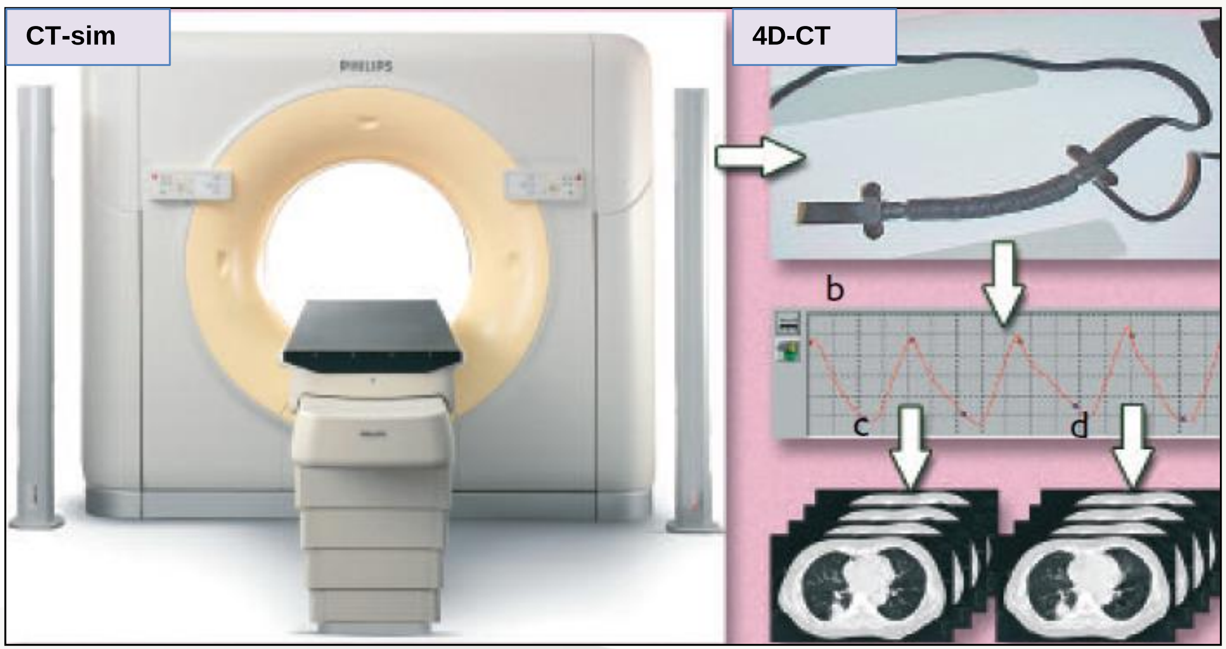
- 15 patients who underwent chemoradiotherapy for pre-operative pancreatic adenocarcinoma at our institution, from 2012 to 2103, were retrospectively selected for this study.

- 3-5 fiducial markers were placed at least five days before the day of simulation.

- Oral and intravenous (IV) contrasts were administered.

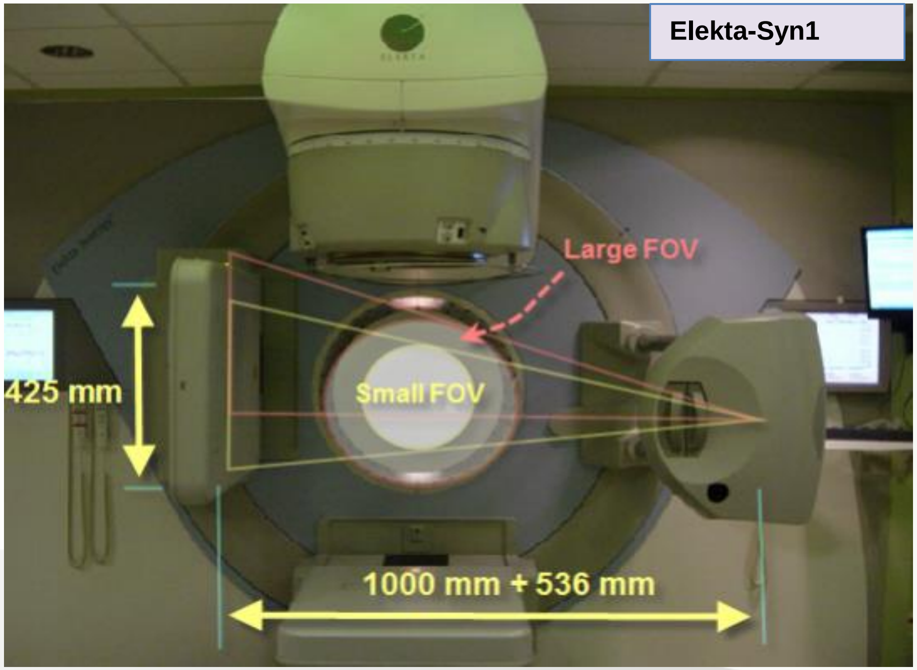
- FBCT and 4D-CT with 10 respiratory phases were acquired using 3 mm slices on a Brilliance CT Big Bore (Phillips Medical System, Eindhoven, The Netherlands).

• GTV was contoured on the FBCT and a margin of 1 cm in all directions was added to create the PTV. The FBCT and 4D-CT were fused using MIMvista to ensure that the motion envelop of the tumor observed from 4D-CT was inside the PTV.



• Treatment plans were designed on the FBCT with 5 IMRT for a prescription of 50.4 Gy at 1.8 Gy/fraction using the Pinnacle 9.0 treatment planning system.

• Treatment was delivered on Elekta, Synergy 1 with daily kV-CBCT using XVI system aligned to the bony anatomy of the planning FBCT to correct for setup errors.



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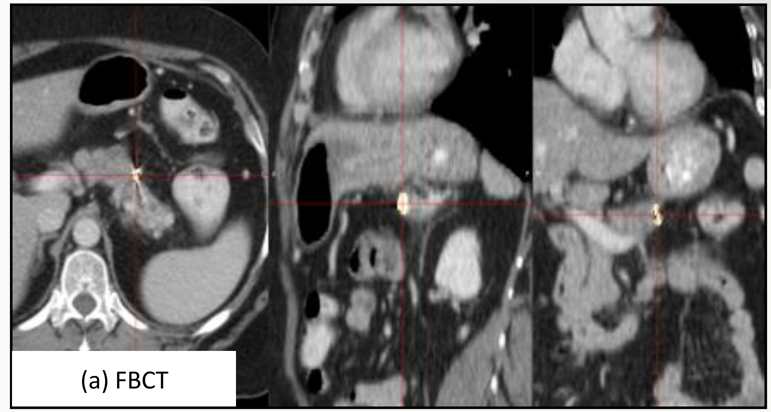
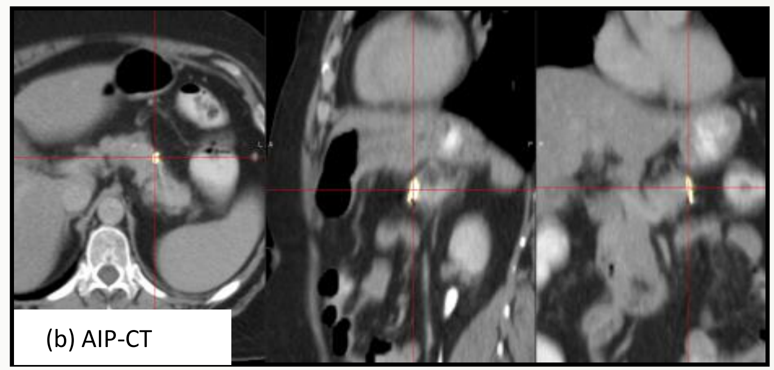
- After treatments, five weekly CBCTs for each patient were exported from the MOSAIQ 2.3 to the MIM workstation.

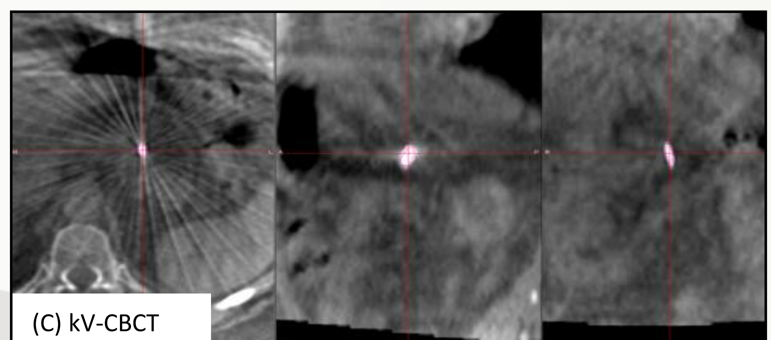
- The fiducial markers on the FBCT, AIP, and CBCT were manually contoured on the MIM workstation.



(a) FBCT



(b) AIP-CT

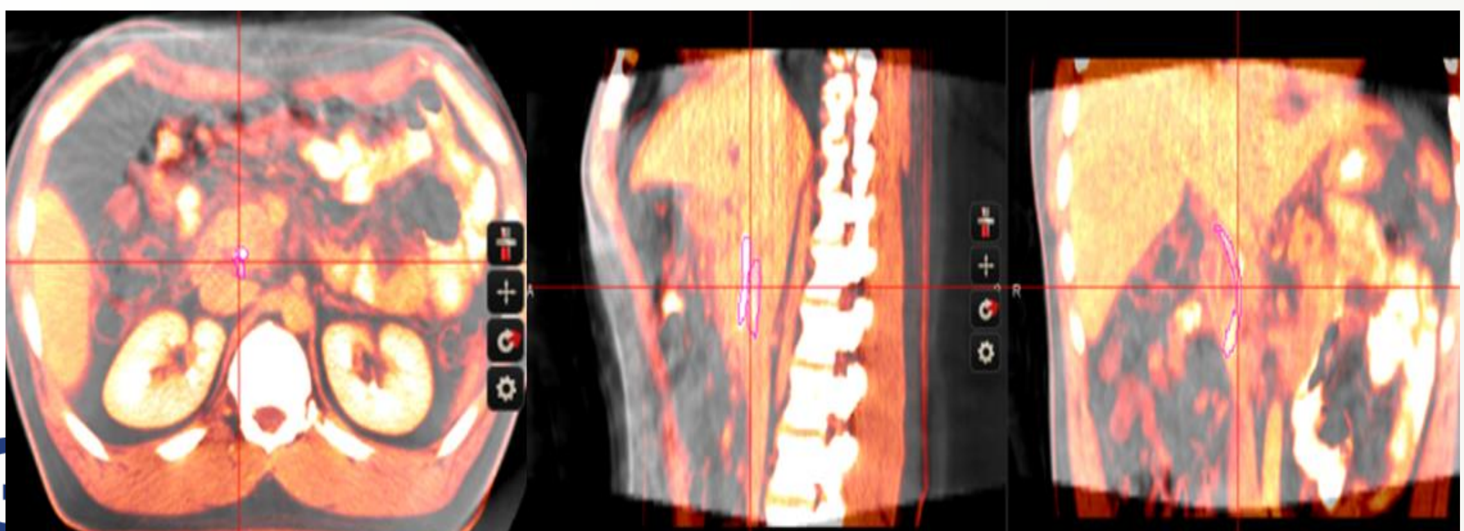


(C) kV-CBCT

- Bony registration, without rotation corrections, using the rigid fusion algorithm from the MIM software were performed between:(1) FBCT and CBCT and (2) AIP and CBCT

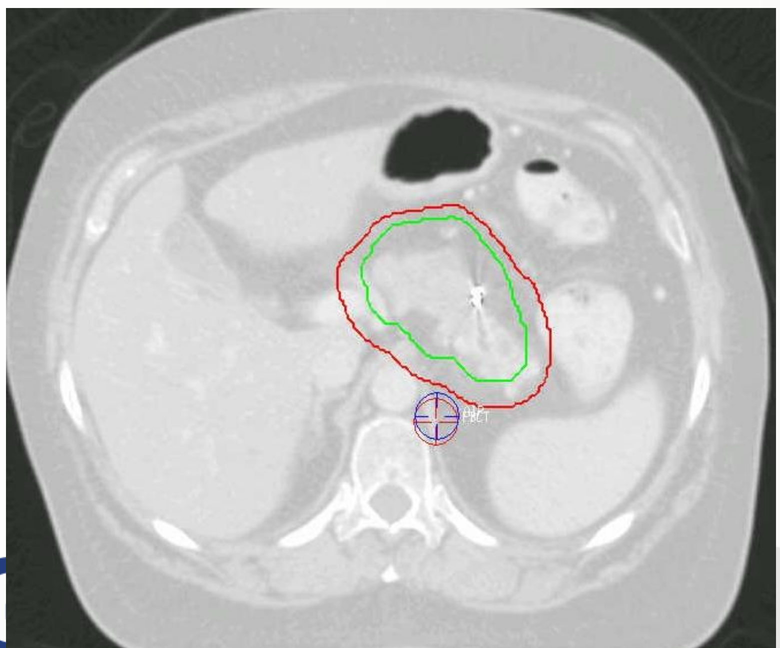
- After registration, the fiducial marker contours were transferred from the FBCT and AIP into the CBCT reference frame.

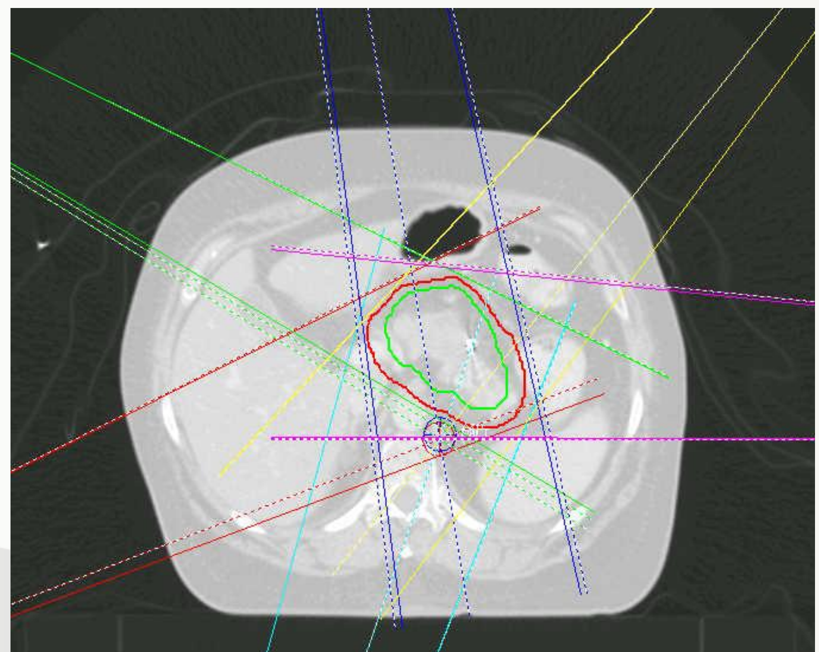
- The COM coordinates of the fiducial maker contours from FBCT, AIP and CBCT were recorded and compared.



- To study the dosimetric impact of using FBCT versus AIP as a reference image set for IGRT:
    - The discrepancies in COM coordinates between FBCT/CBCT and AIP/CBCT were translated into isocenter shifts in the corresponding treatment plan, and the dose was recalculated.

- Only fractions with differences > 3 mm in any directions were included in dosimetric analysis. No dosimetric impact was noticed for fractions with differences < 3mm.

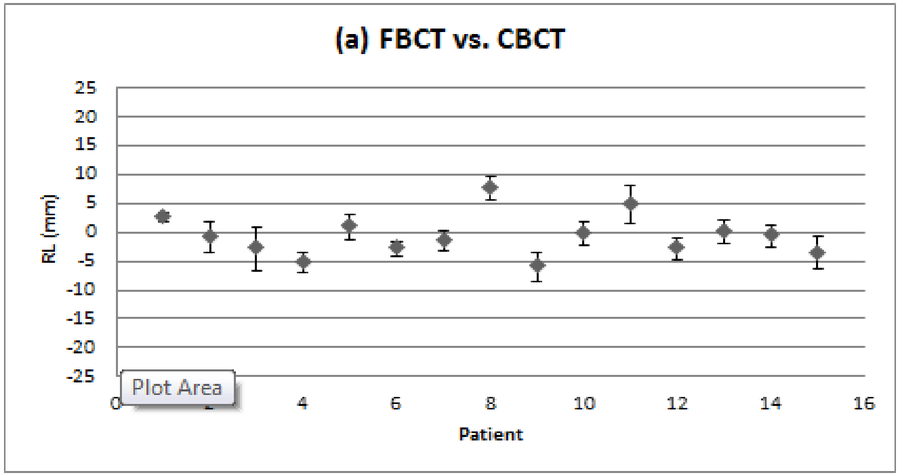


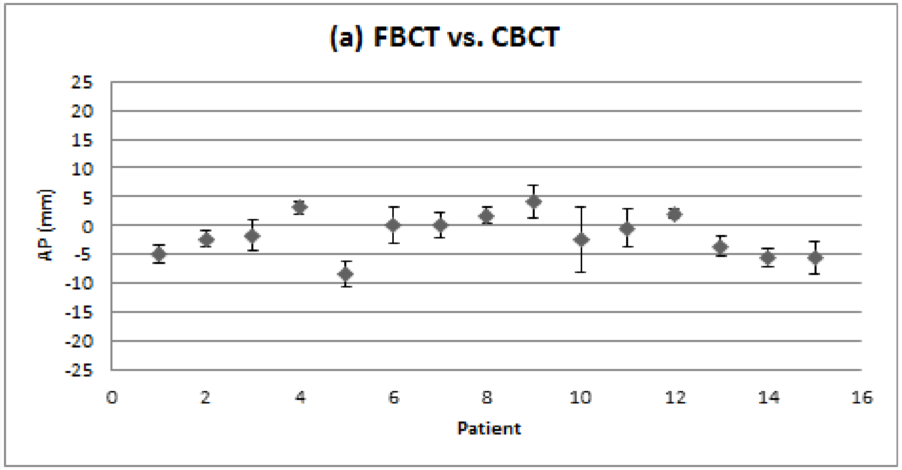


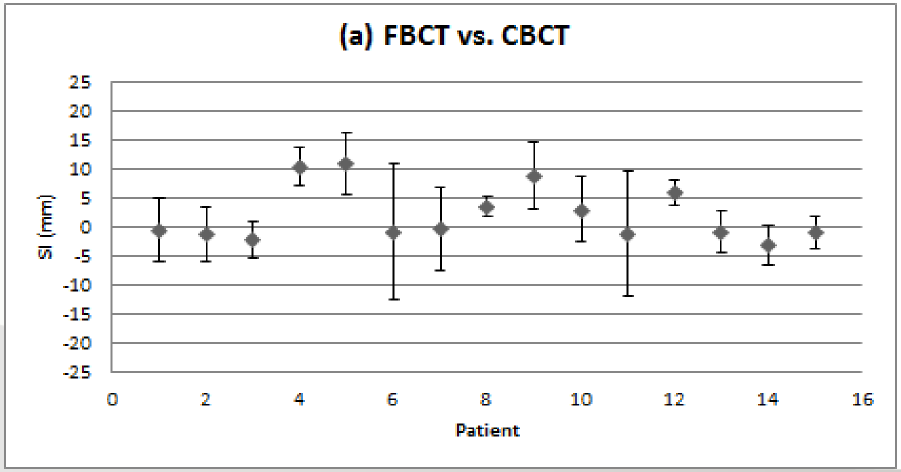
FBCT versus CBCT

- After correcting for setup errors with bony registration.
- Shifts in implanted marker's COMs between FBCT and CBCT included the:
  - ✓ Interfractional tumor displacement
  - ✓ Potential systematic uncertainties of the COMs of the markers.
  - ✓ Residual bony registration uncertainties .

	RL	AP	SI
AVG (mm)±SD	2.9±2.3	2.8±2.3	3.6±3.7
Min (mm)	0.0	0.0	0.2
Max(mm)	7.6	8.4	11.0



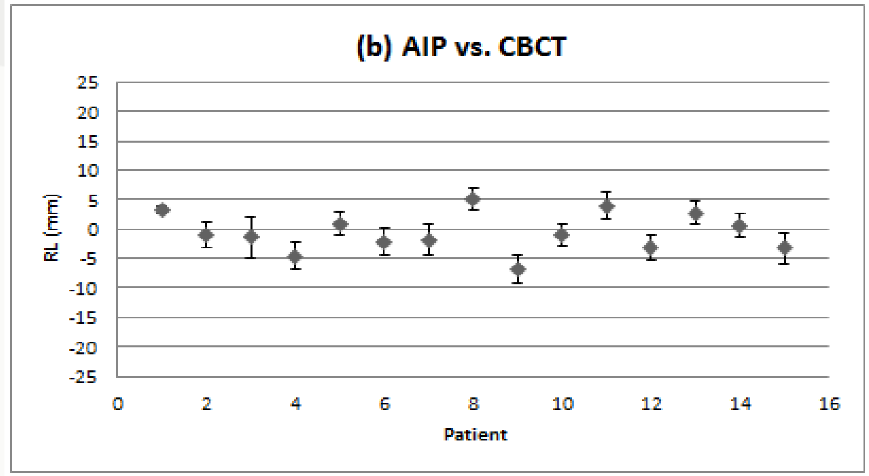


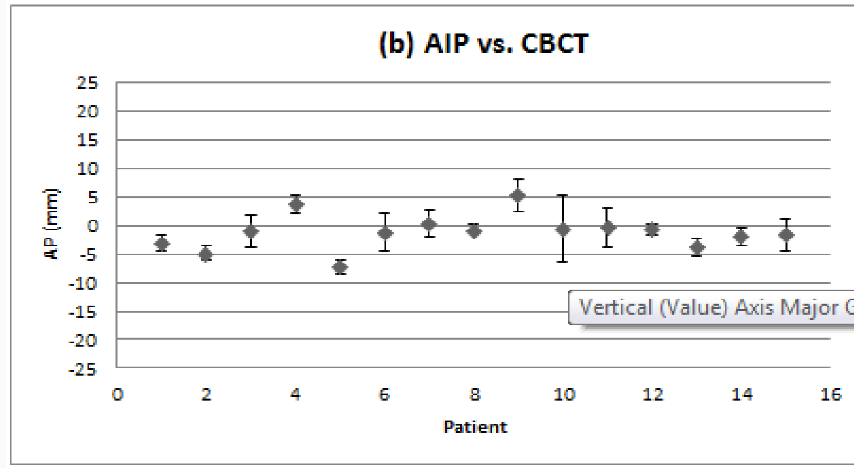


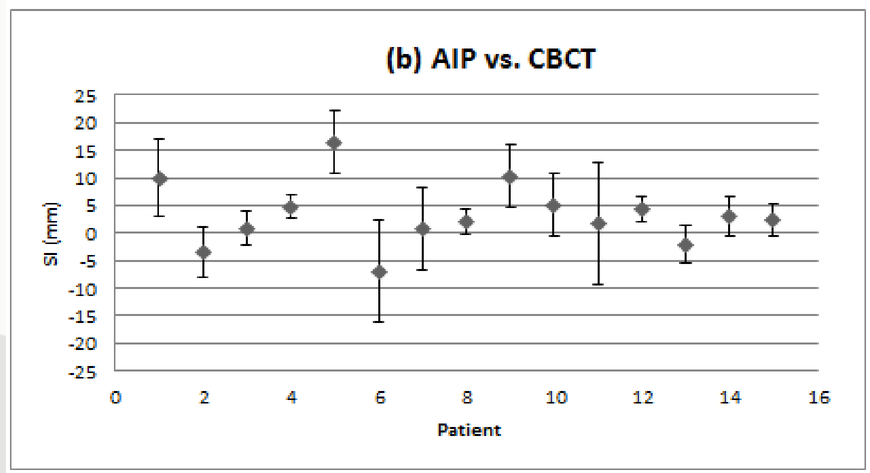
AIP versus CBCT

- After correcting for setup errors with bony registration.
- Shifts in implanted marker's COMs between FBCT and CBCT included the:
  - ✓ Interfractional tumor displacement
  - ✓ Residual bony registration uncertainties

	RL	AP	SI
AVG (mm)±SD	2.7±1.8	2.5±2.1	4.9±4.4
Min (mm)	0.6	0.4	0.7
Max(mm)	6.8	7.3	16.5



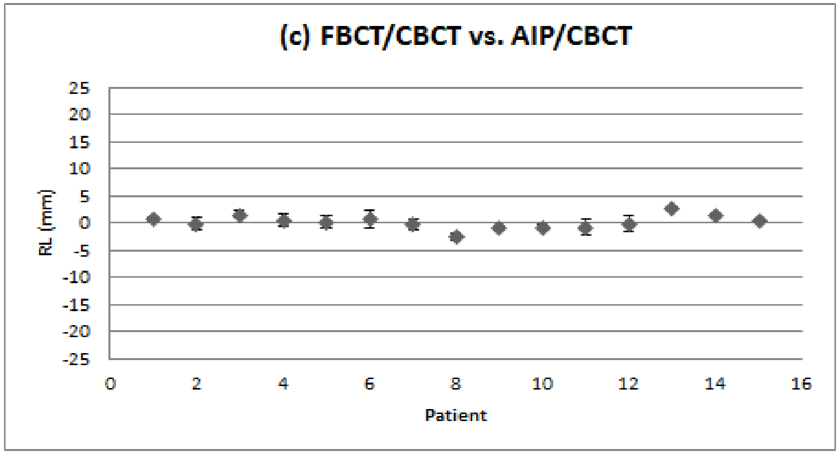


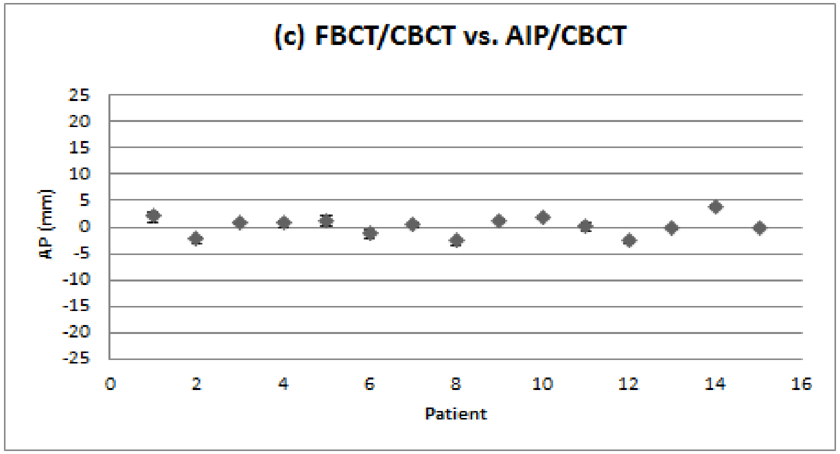


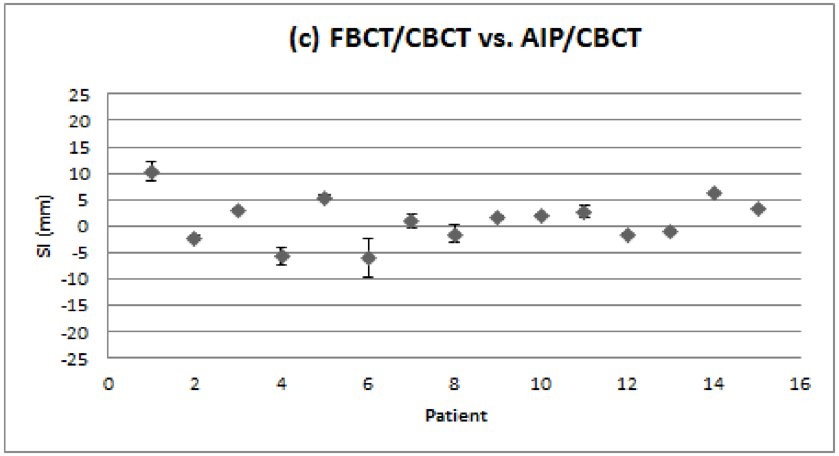
FBCT/CBCT versus AIP/CBCT

- After correcting for setup errors with bony registration.
- Shifts in implanted marker's COMs between FBCT and CBCT included the:
  - ✓ <u>Potential systematic uncertainties of the COMs of the markers.</u>

	RL	AP	SI
AVG (mm)±SD	0.9±0.8	1.4±1.1	3.6±2.6
Min (mm)	0.1	0.1	1.0
Max(mm)	2.8	3.7	10.4







Dosimetric impact

- In 20 of 75 fractions, the COM discrepancies > 3mm in any direction.
- The difference represents the systematic uncertainty in the treatment isocenter if the daily CBCT is aligned to the markers of the FBCT
- The average PTV100% was reduced by 5.3 ± 3.1%

Patient Number, Fraction Numbers	PTV $_{100\%}$ using FBCT as a reference IGRT	PTV $_{100\%}$ using AIP as a reference IGRT	Difference (%)
1, (1,3)	85.0	97.2	12.6
2, (3)	87.3	96.3	9.4
3, (2-5)	93.9	97.4	3.5
4, (1-5)	93.2	98.1	4.9
5, (1-5)	91.9	96.0	4.3
6, (4-5)	90.5	95.1	4.9

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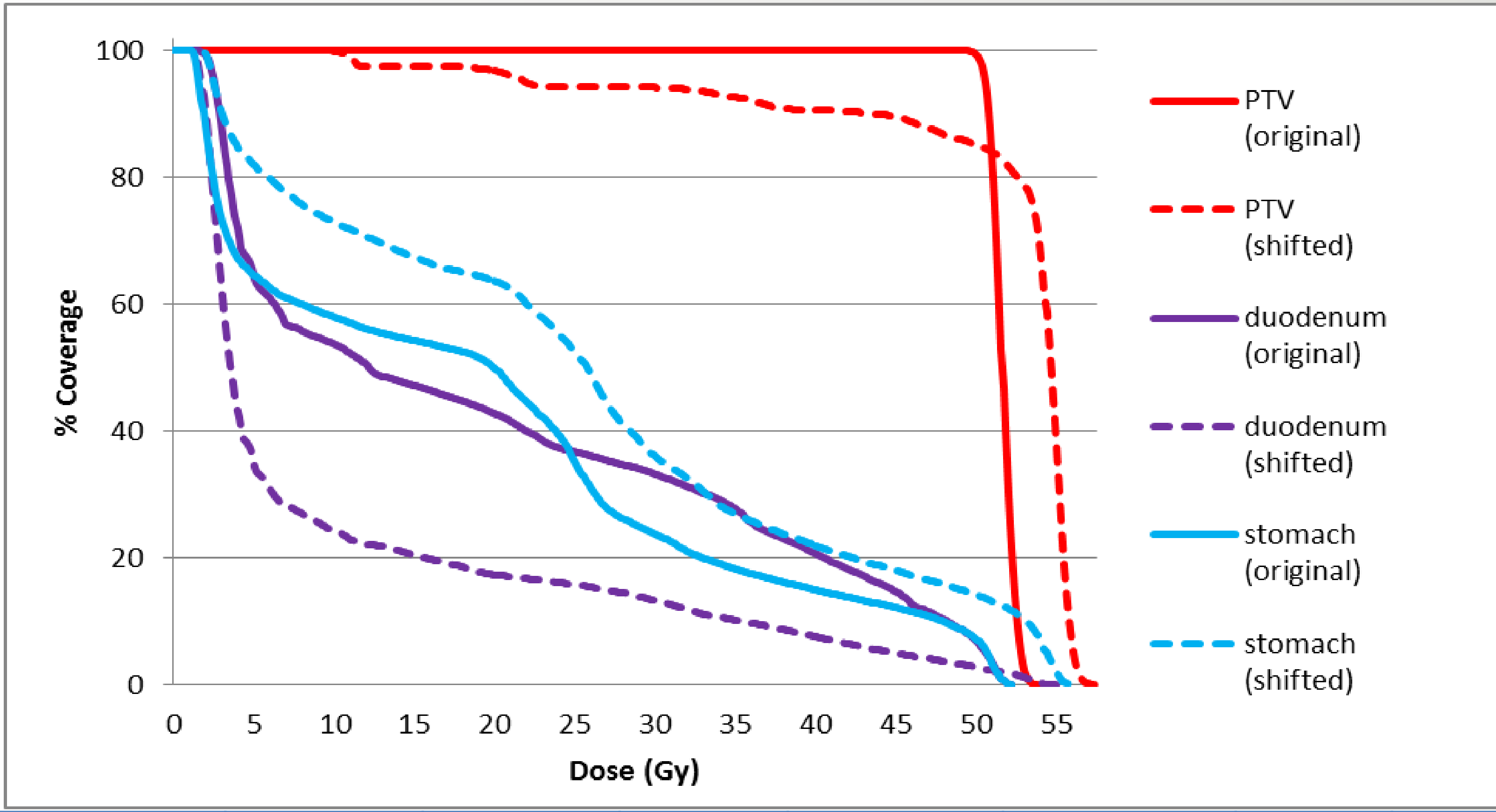

Average ± SD	Bilateral Kidneys mean dose (Gy)	Bilateral Kidneys $V_{20} \leq 32\%$	Liver Mean Dose (Gy)	Stomach Maximum Dose (Gy)	Duodenum Maximum Dose (Gy)	Small Bowel ($V_{50-54} \leq 2\%$)	Cord Maximum Dose (Gy)
Original plan[1]	9.1±3.9	8.5±7.3%	9.6±4.6	10.7±8.6	52.3±0.7	0	29.4±8.7
Shift plan on FBCT[2]	9.4±4.5	9.7±8.5%	8.6±5.0	12.3±9.9	52.4±0.7	0	28.9±8.5
p-value	0.96	0.82	0.80	0.01	0.55	n/a	0.01

Conclusions

- The acquisition of the CBCT takes about one to two minutes that includes many respiratory cycles.

- The COMs of implanted markers represent an average respiratory tumor position, similar to the AIP from 4D-CT.

- FBCTs are acquired in a short time that could capture the implanted markers in any phase of the respiratory cycle.

- In this study, we quantified the COM discrepancies between FBCT and AIP in the reference frame of the same CBCT to estimate the systematic uncertainties that may result from using the FBCT as the reference CT for image-guided tumor localization.

- The COM discrepancies in marker positions varied among patients

- The COM discrepancies in the COMs of the implanted markers when using FBCT or AIP as reference images for IGRT can impact the dosimetry of the PTV and the surrounding critical organs.

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Conclusions

- AIP can be used as the planning CT and the reference CT for IGRT.

- That may introduce some clinical challenges, including degraded image quality and potential inaccuracy of electronic density for planning.

- AIP was compared with the FBCT for contouring organs at risk and radiation treatment planning for SBRT in the lung and concluded no significant differences between the two sets.

- Compared the AIP and FBCT for treatment planning and dose calculations for lung SBRT and concluded that the dosimetric characteristics are similar for both data sets.

- Similar studies for pancreatic tumors are needed to demonstrate the feasibility of using AIP for treatment planning and IGRT.

- AIP is a synthetic CT, some CT-simulators may not be able to create AIP, and to support the function of direct placing of the isocenter on the synthetic CT during virtual simulation.

Thank You
Any Questions?