Trans-perineal ultrasound guidance for prostate radiotherapy: technology, performance, promise, and challenges

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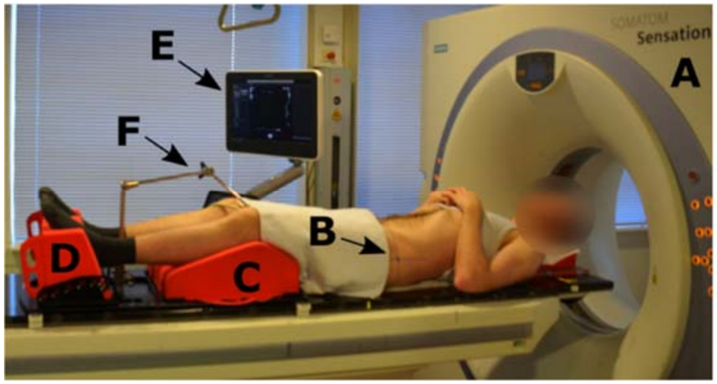

Some of the work presented here was supported by a research grant from Elekta.

To be discussed:

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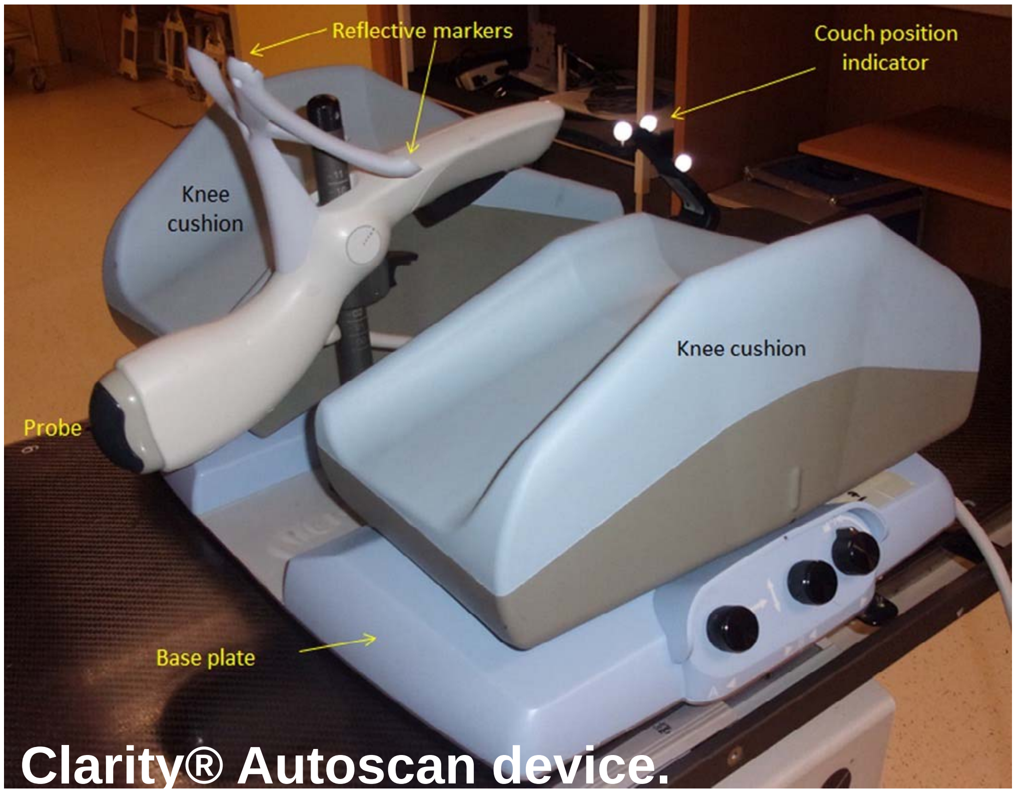
- Trans-perineal ultrasound guidance (TPUS): technology

- TPUS Inter-fraction IGRT
  - Process
  - Performance
  - Potential venues for improvement

- TPUS intra-fractional imaging and tracking
  - Phantom evaluation: design and challenges
  - In-vivo evaluation: designs, results, and challenges

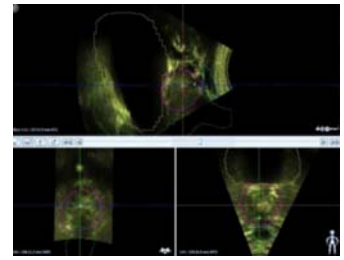
- Summary

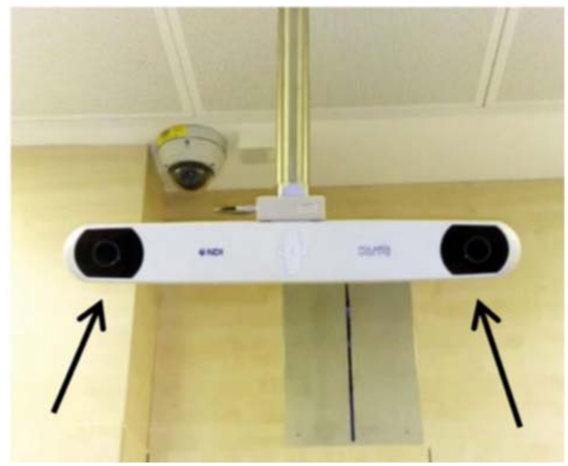
Trans-perineal Ultrasound (TPUS) IGRT technology



Clarity® Autoscan device.

M. Fargier-Voiron et al., Physica Medica 32(2016) 499–505





Li M et al, Strahlenther Onkol (2017) 193:221–228

TPUS IGRT process

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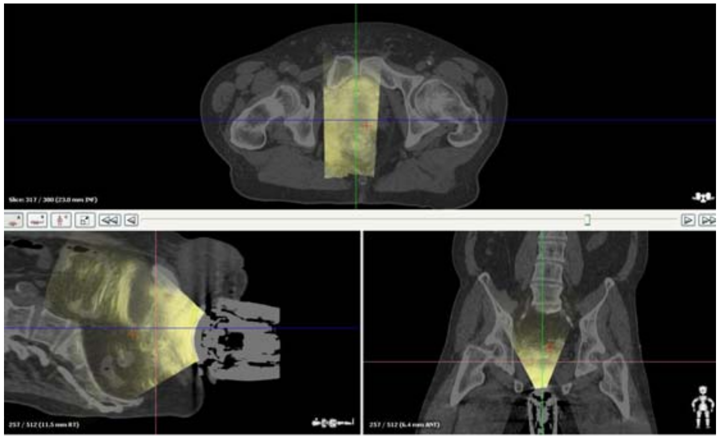

TPUS IGRT process

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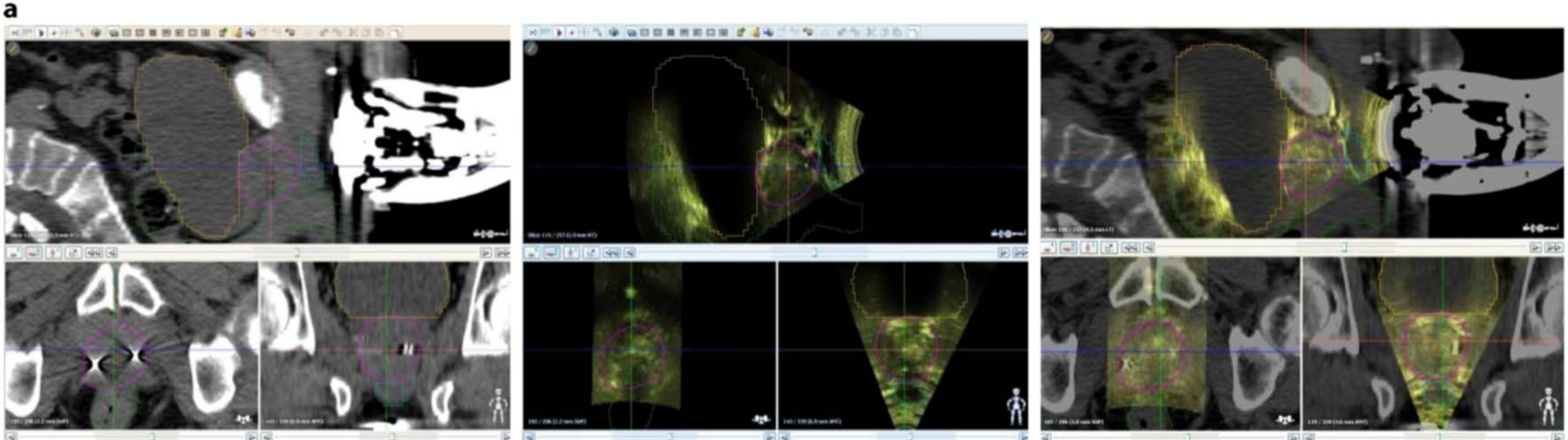
Automatic fusion of simulation three-dimensional ultrasound (3DUS) to CT in the planning phase. RT structures, beams (isocenter), and 3DUS all referenced in world (room) coordinate system.

a



Li M et al, Strahlenther Onkol (2017) 193:221–228

CT-3DUS fusion establishes desired position of 3DUS defined target (prostate) with respect to the treatment isocenter. This position needs to be reproduced prior at treatment.

TPUS IGRT process

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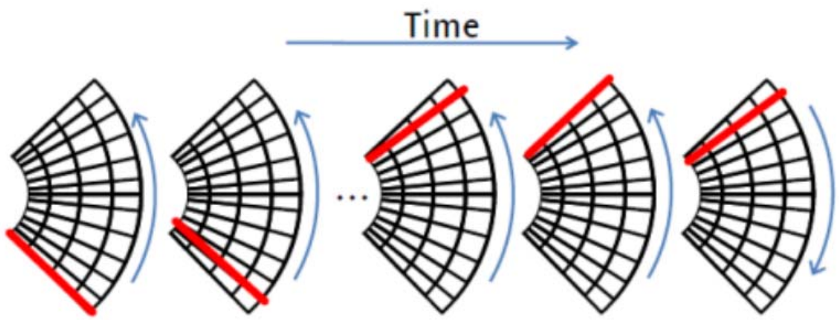
Green volume: prostate contoured at planning.
Red volume: prostate manually localized in pre-treatment 3DUS. Indicates current prostate position with regard to treatment isocenter.

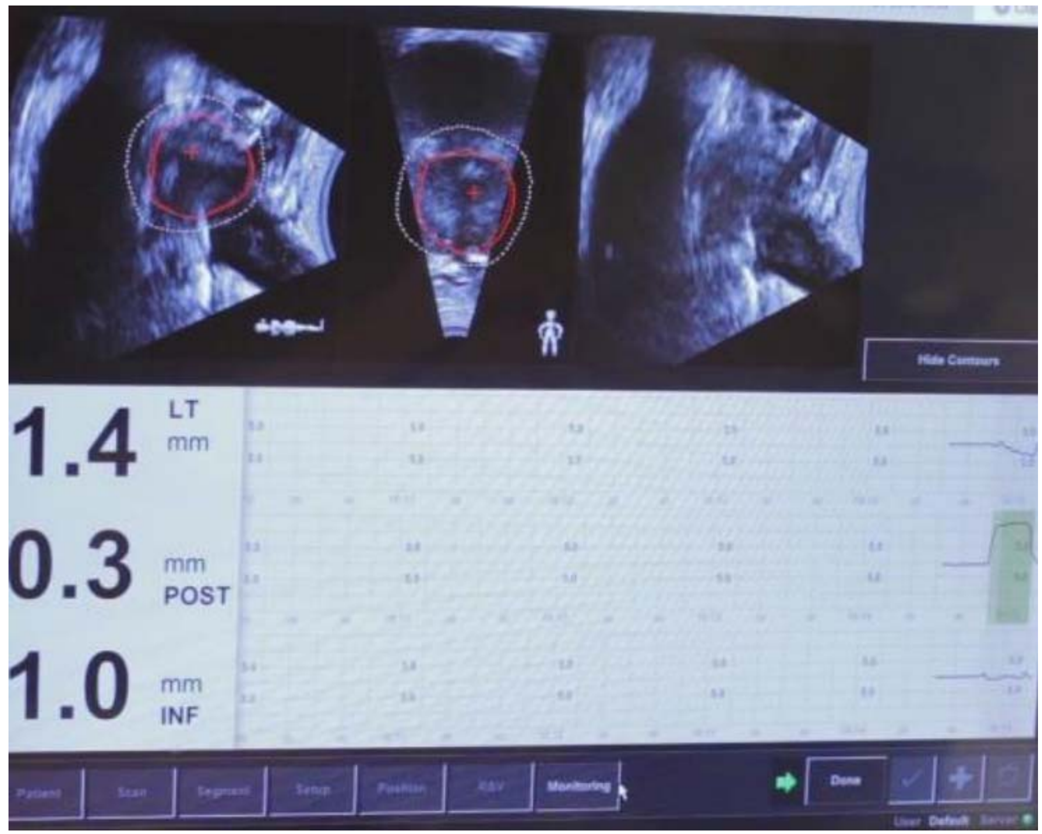
b

Li M et al, Strahlenther Onkol (2017) 193:221–228

Accuracy of shifts depends on how well the user localizes (segments) prostate in pre-treatment 3DUS.

TPUS IGRT Process





Lachaine, M. & Falso, T. Intrafractional prostate motion management with the Clarity autoscan system. Med. Phys. Int. 1, 72-80 (2013).

US imaging interference with anatomy

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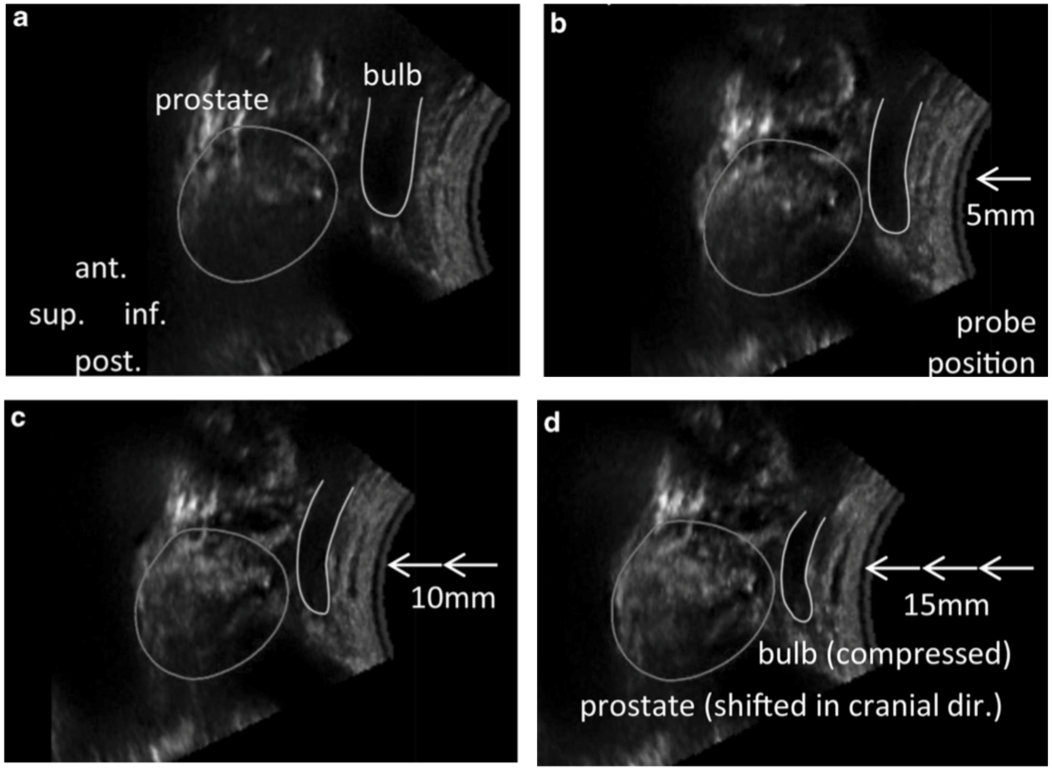

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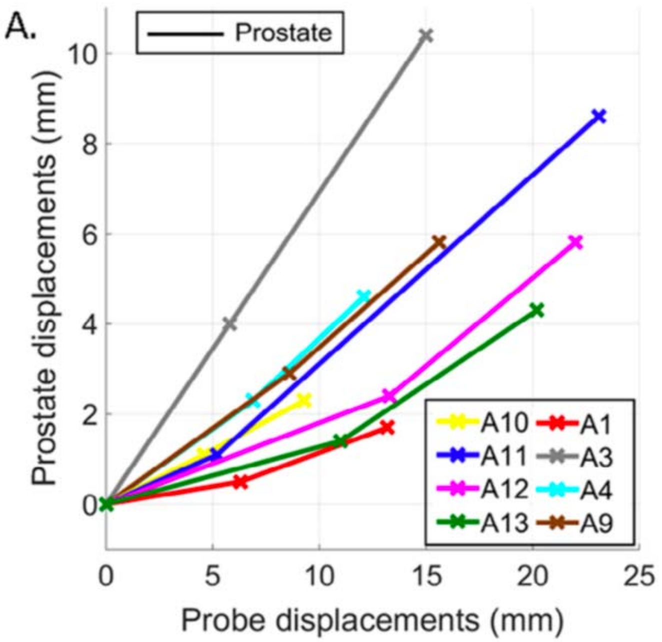
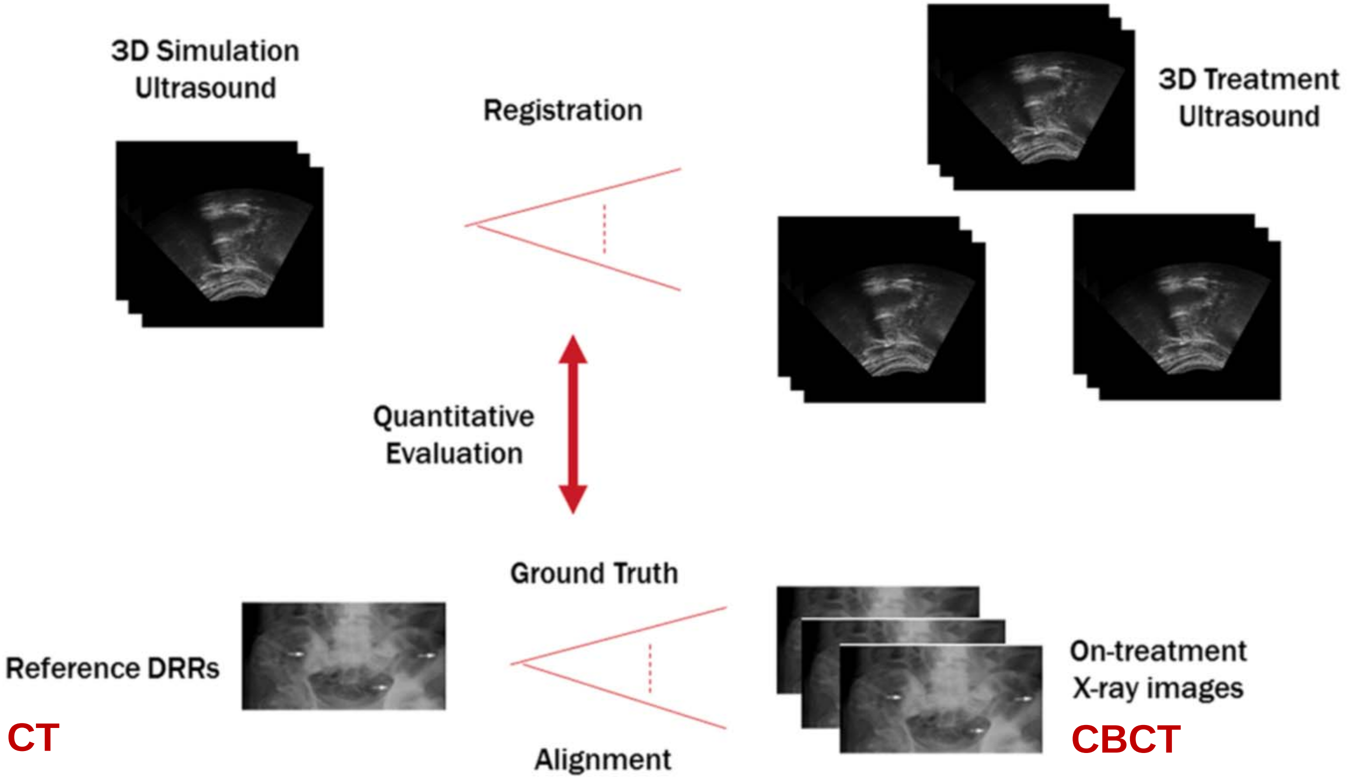


M. Fargier-Voiron et al., Physica Medica 32(2016) 499–505

Prostate position changes with pressure but remains known at all times.

Accuracy of 3D TPUS IGRT



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N. Zhu, et al, Technology in Cancer Research & Treatment, V 18: 1-11, 2019
Zhou et al. Radiation Oncology (2019) 14:22

Accuracy of 3D TPUS IGRT

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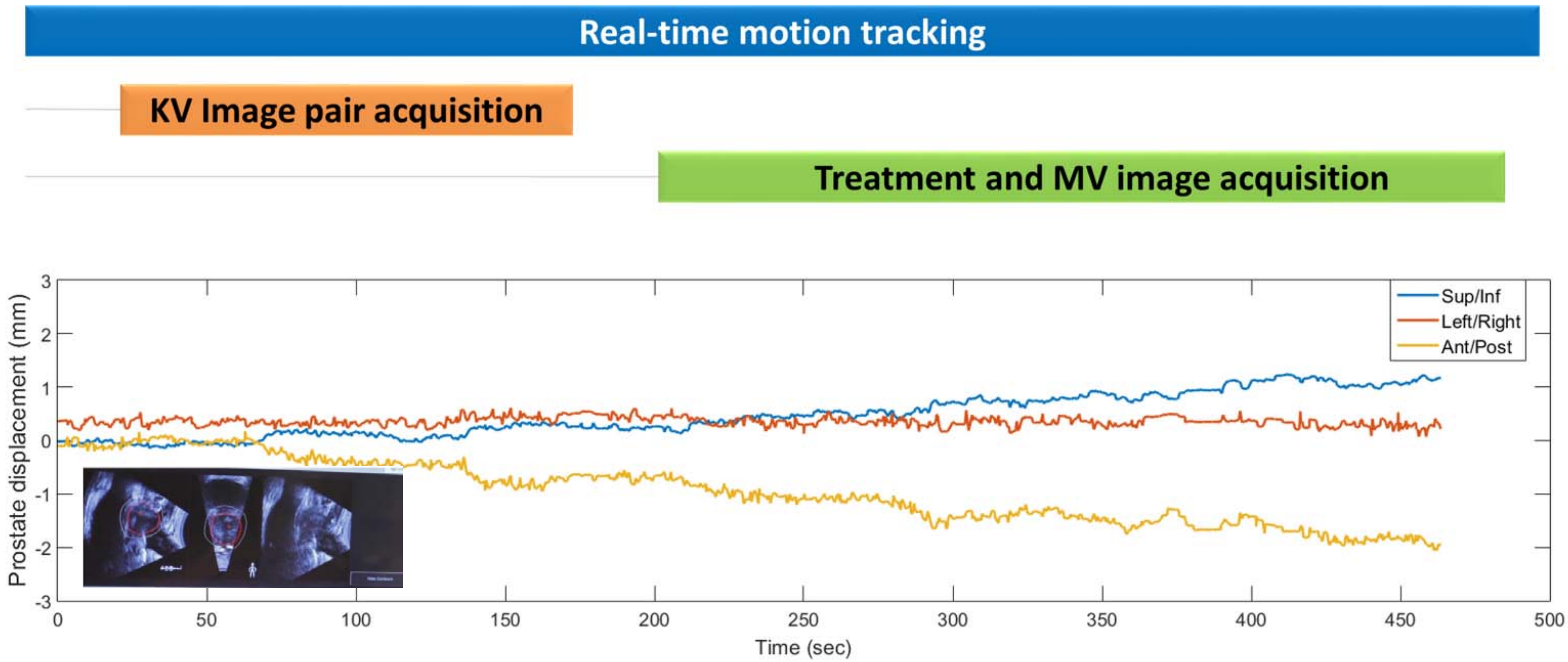

N. Zhu, M. Najafi, B. Han, S Hancock, and D Hristov, PhD, Technology in Cancer Research & Treatment, V 18: 1-11, 2019

Accuracy of 3D TPUS IGRT

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Study	Percent Agreement within 5 (3) mm			
	Superior-Inferior	Anterior-Posterior	Left-Right	Radial
Fargier-Voiron et al.	95	77	95	
Zhou et al.	67	77	92	
Li et al.	99 (86)	99 (91)	99 (93)	
Zhu et al.				60.0

M. Fargier-Voiron et al., Physica Medica 32(2016) 499–505

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N. Zhu, et al, Technology in Cancer Research & Treatment, V 18: 1-11, 2019

Zhou et al. Radiation Oncology (2019) 14:22

Large variability. Accuracy likely to be considerate currently inadequate for prostate IGRT.

Accuracy of 3D TPUS IGRT

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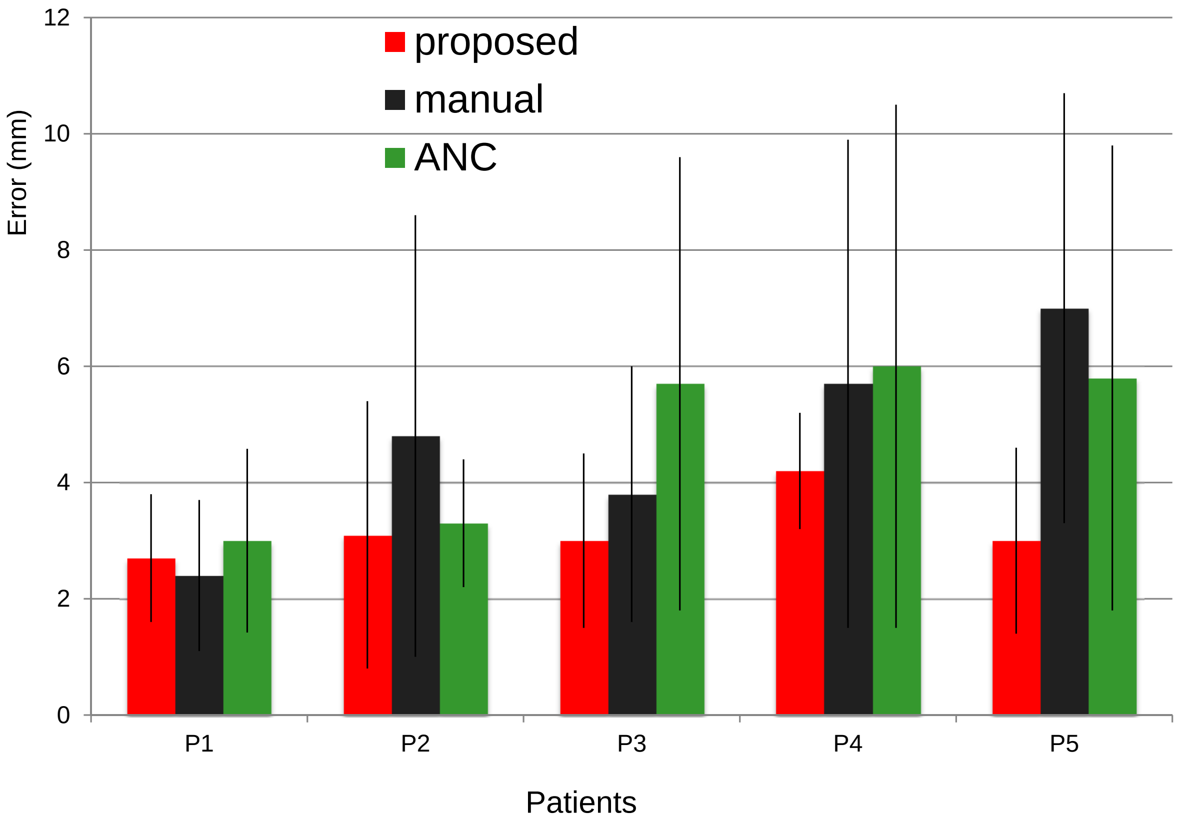
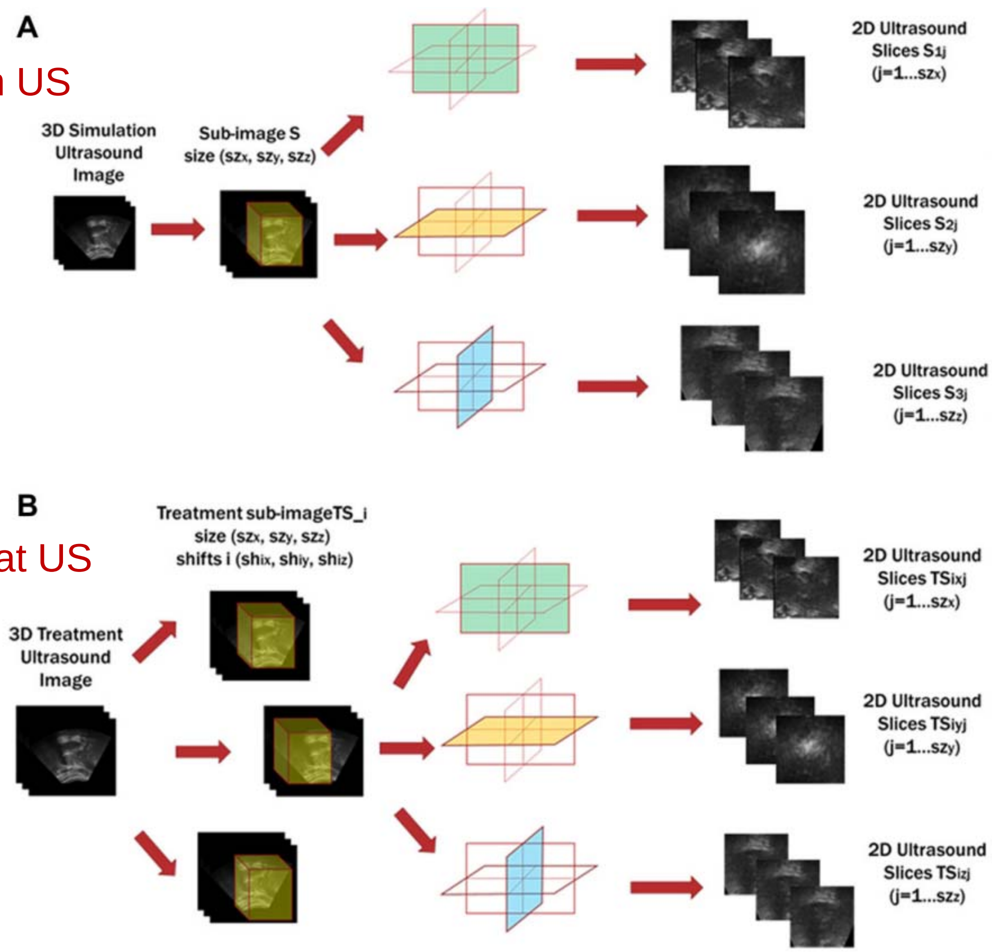
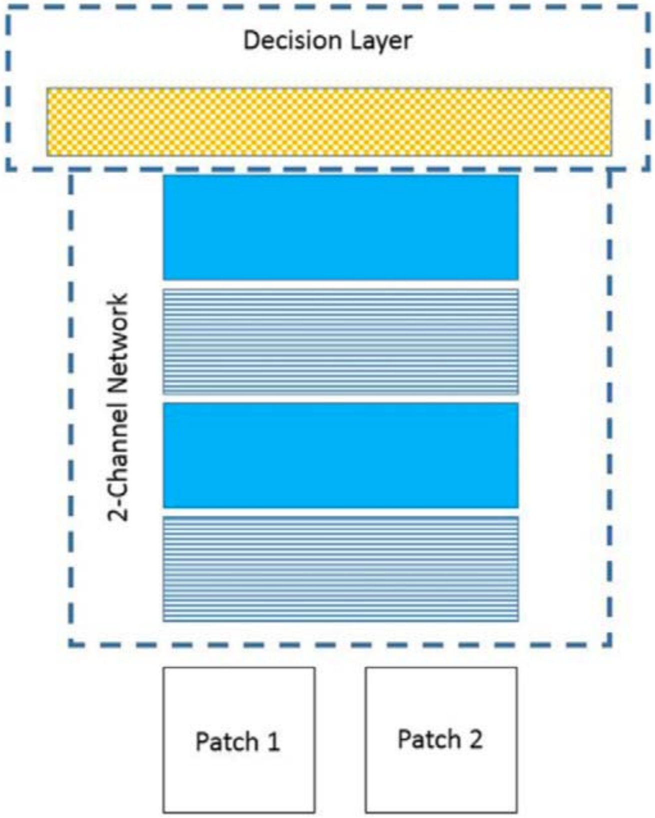


ANC: Normalized similarity metric in Elastix.
proposed: pre-trained CNN

N. Zhu, et al, Technology in Cancer Research & Treatment, V 18: 1-11, 2019

Accuracy of 3D TPUS IGRT: need for improvement





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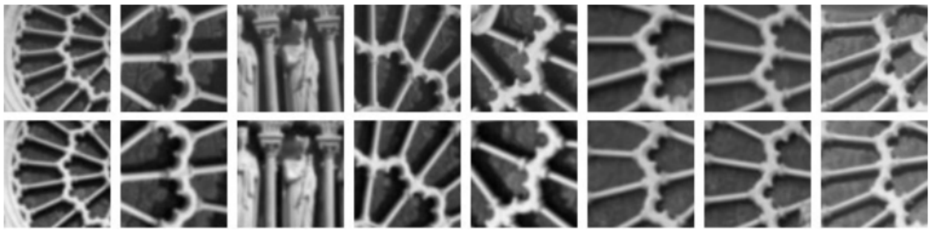
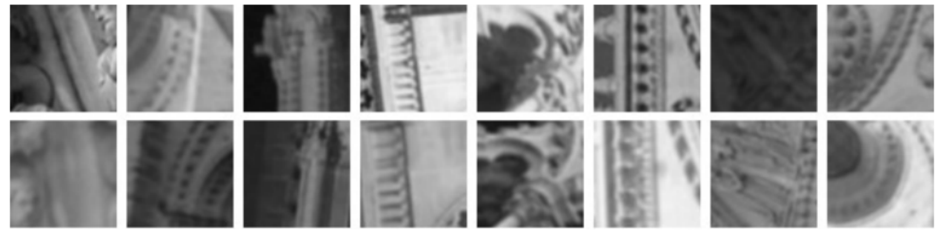
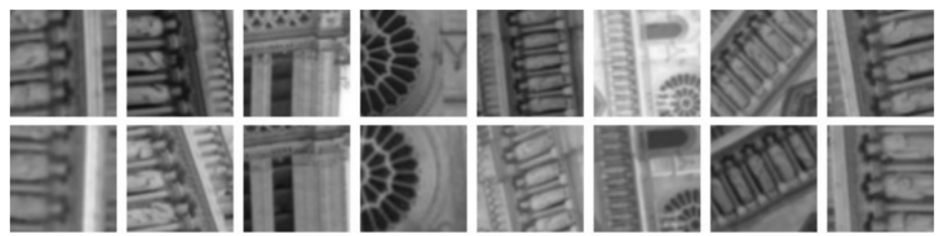


(a) true positives



(b) false negatives

(c) true negatives



(d) false positives

Accuracy of 3D TPUS IGRT: need for improvement

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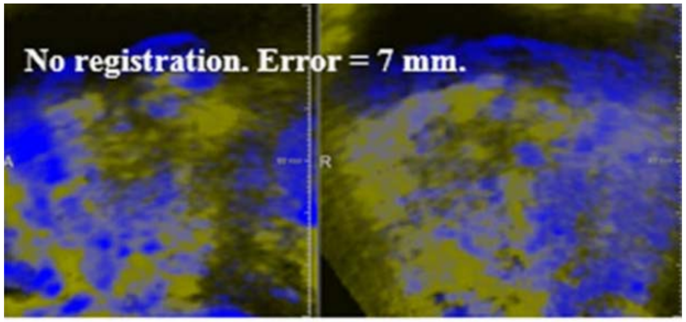

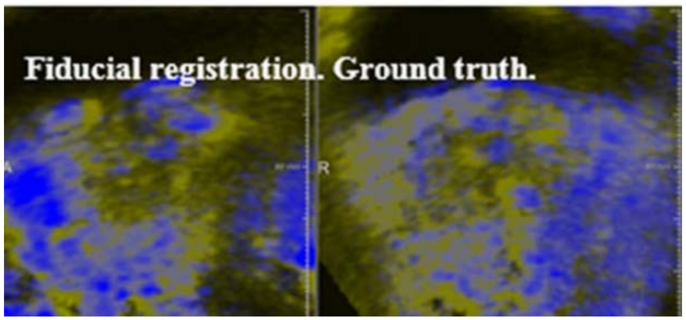

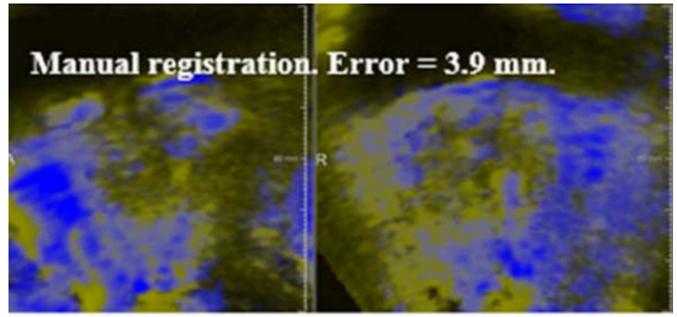

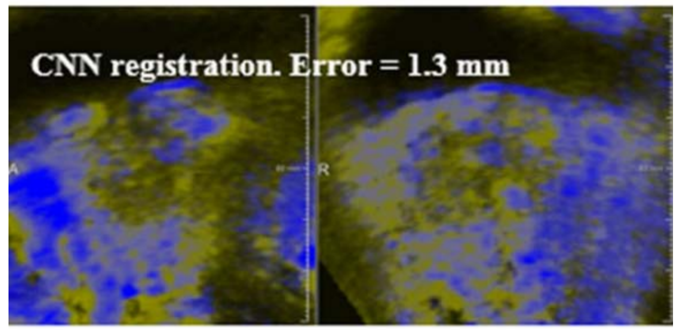

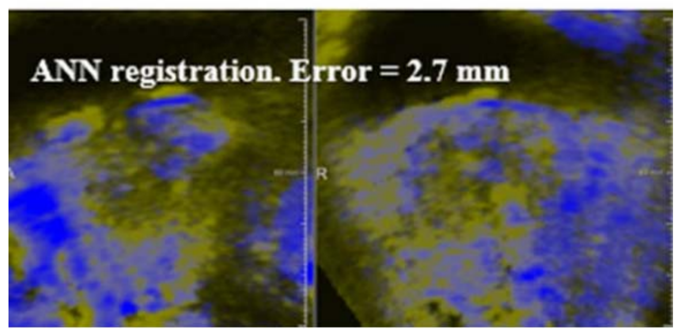

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N. Zhu, et al, Technology in Cancer Research & Treatment, V 18: 1-11, 2019

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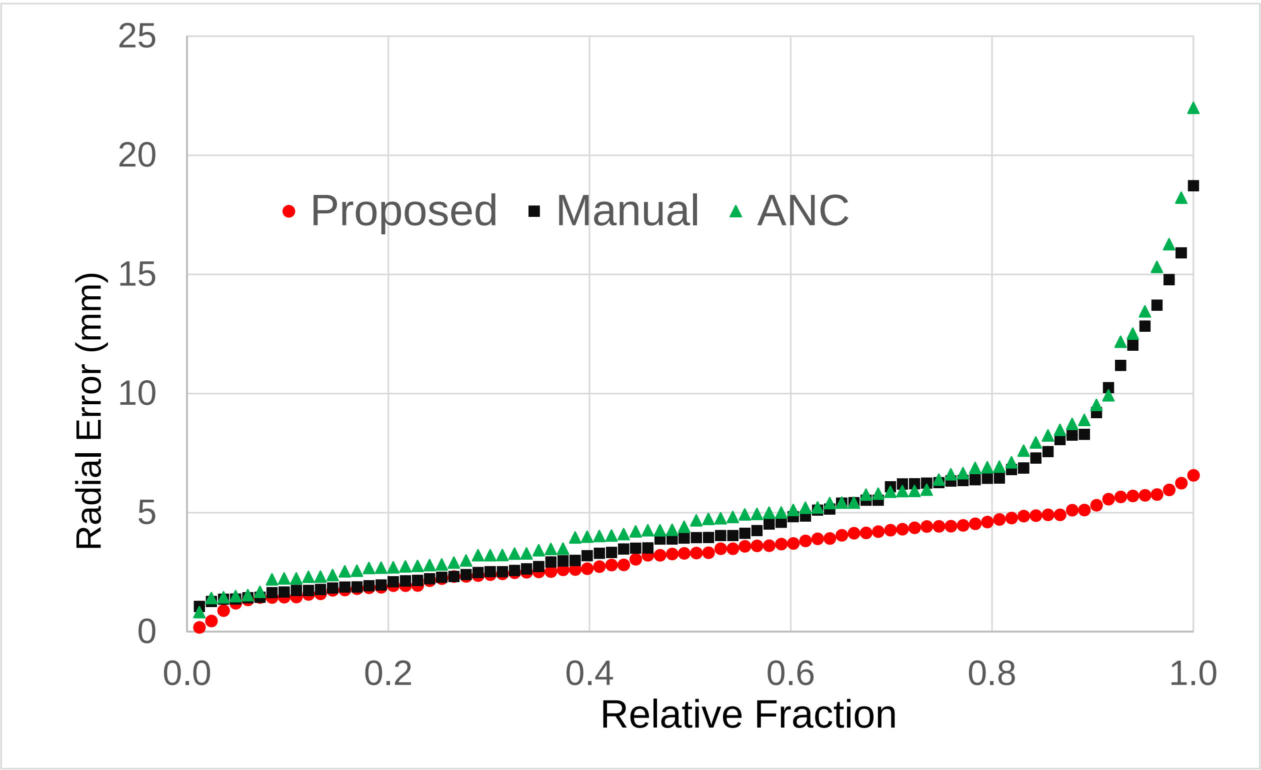

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Similarity based on pre-trained CNN decrease error but further improvement is needed.

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3D TPUS IGRT tracking: how good is it?

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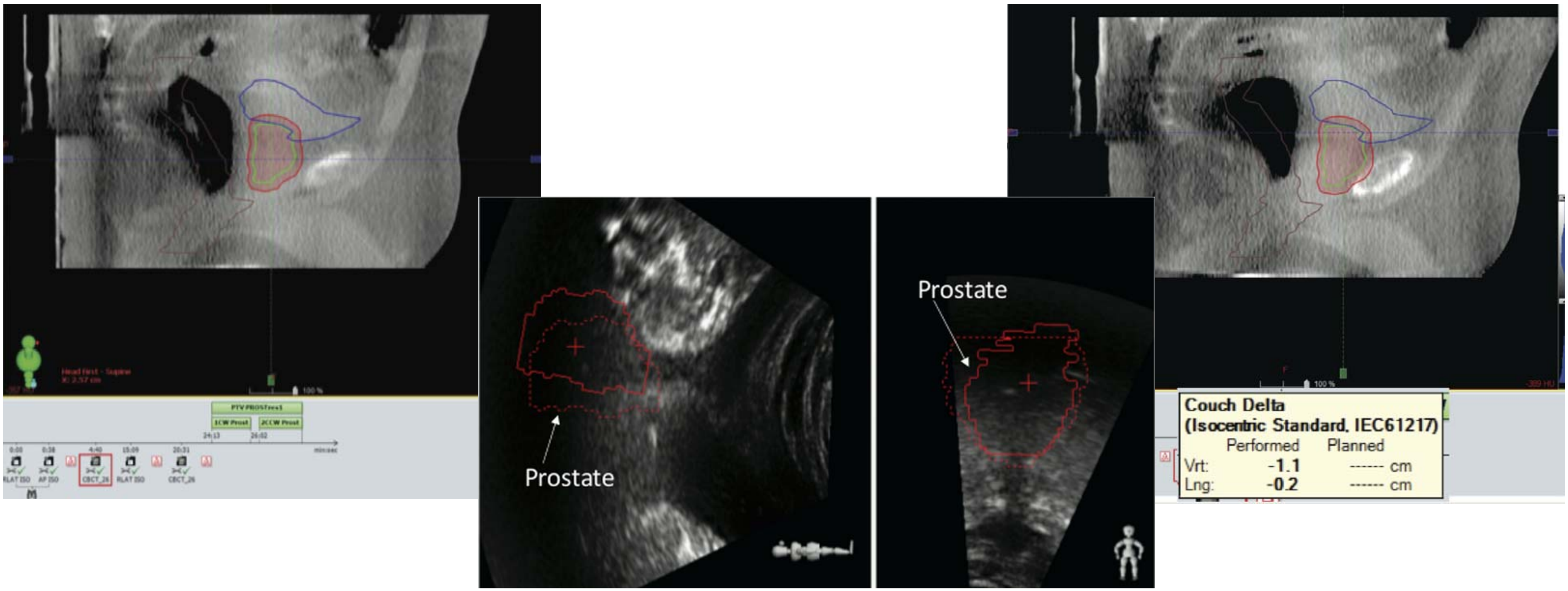

Occasional large and sudden transitions occur.

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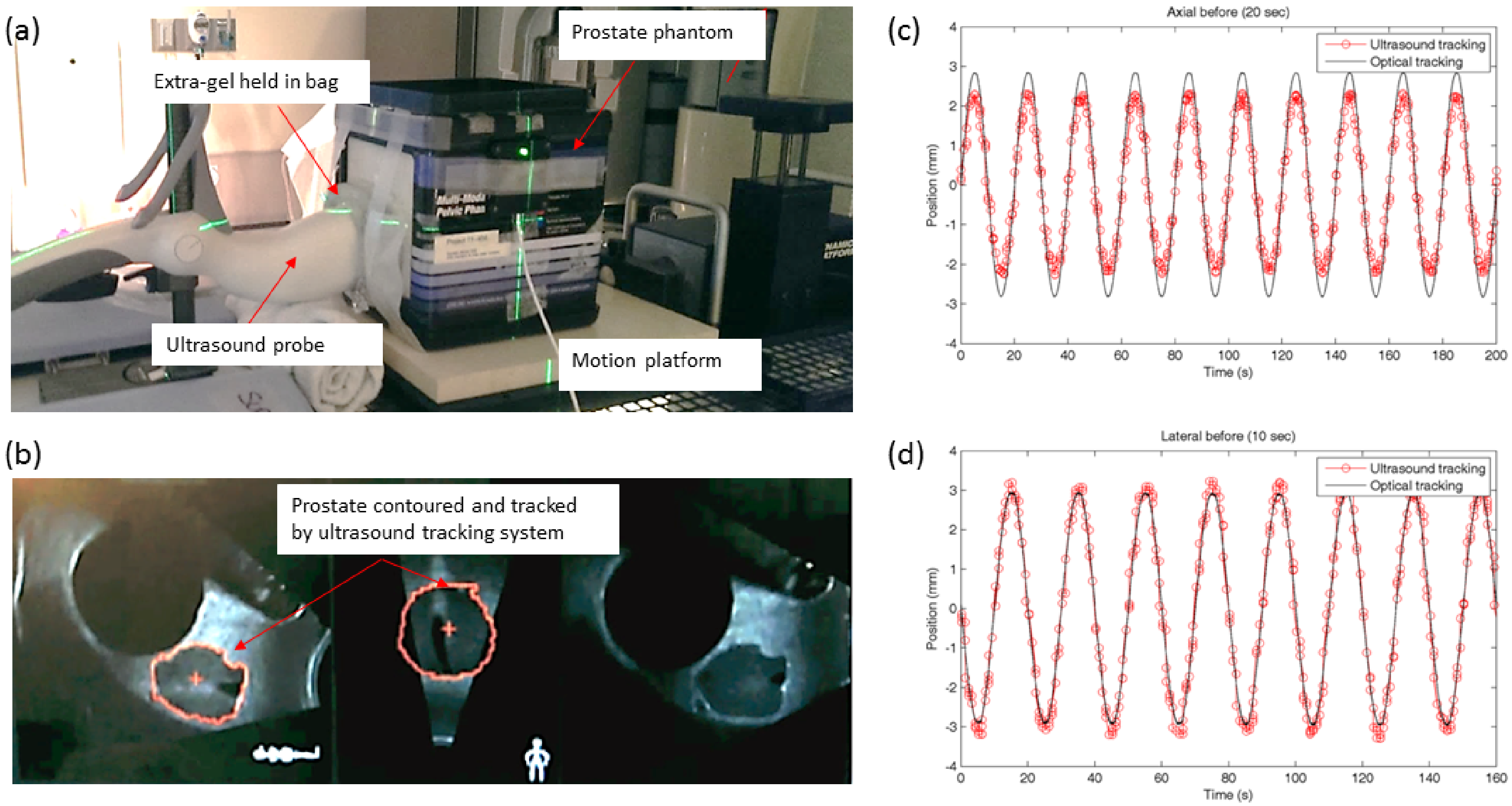

Lachaine, M. & Falso, T. Intrafractional prostate motion management with the Clarity Autoscan system. Med. Phys. Int. 1, 72-80 (2013).

Amy S. Yu, Mohammad Najafi, Dimitre H. Hristov, and Tiffany Phillips*, Techn. in Cancer Res. & Treat., 2017, Vol. 16(6) 1067–1078*

3D TPUS IGRT tracking: how good is it?

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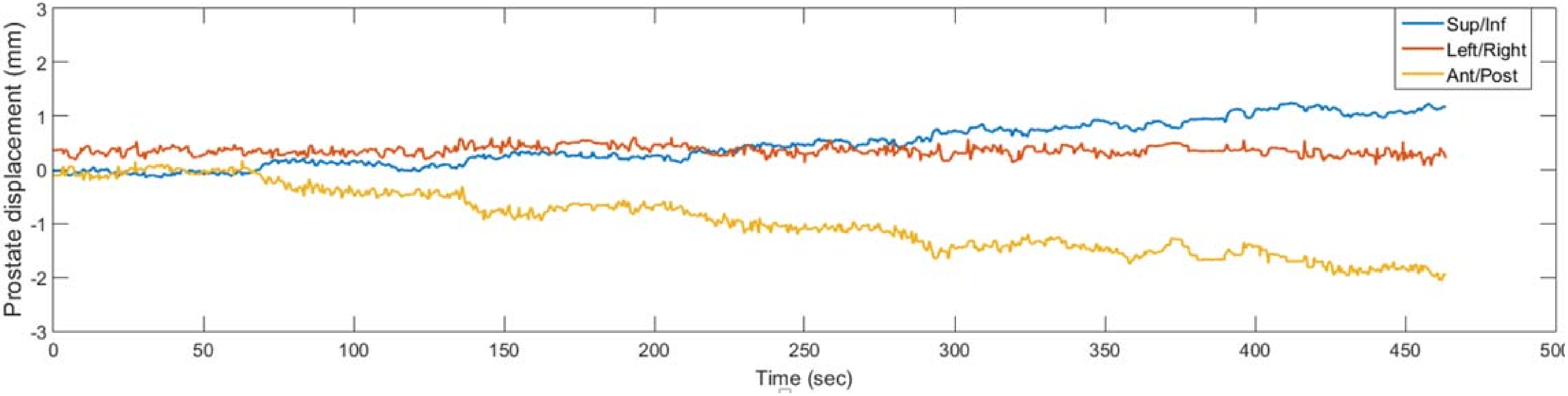
Challenges for experimental designs



Biston, M.-C., et al., Comparison of electromagnetic transmitter and ultrasound imaging for intrafraction monitoring of prostate radiotherapy. Radiotherapy and Oncology, 2019. 136: p. 1-8.

Han, B., et al., Evaluation of transperineal ultrasound imaging as a potential solution for target tracking during hypofractionated radiotherapy for prostate cancer. Radiat Oncol, 2018. 13(1): p. 151.

Grimwood, A., et al., In Vivo Validation of Elekta's Clarity Autoscan for Ultrasound-based Intrafraction Motion Estimation of the Prostate During Radiation Therapy. Int J Radiat Oncol Biol Phys, 2018. 102(4): p. 912-921.

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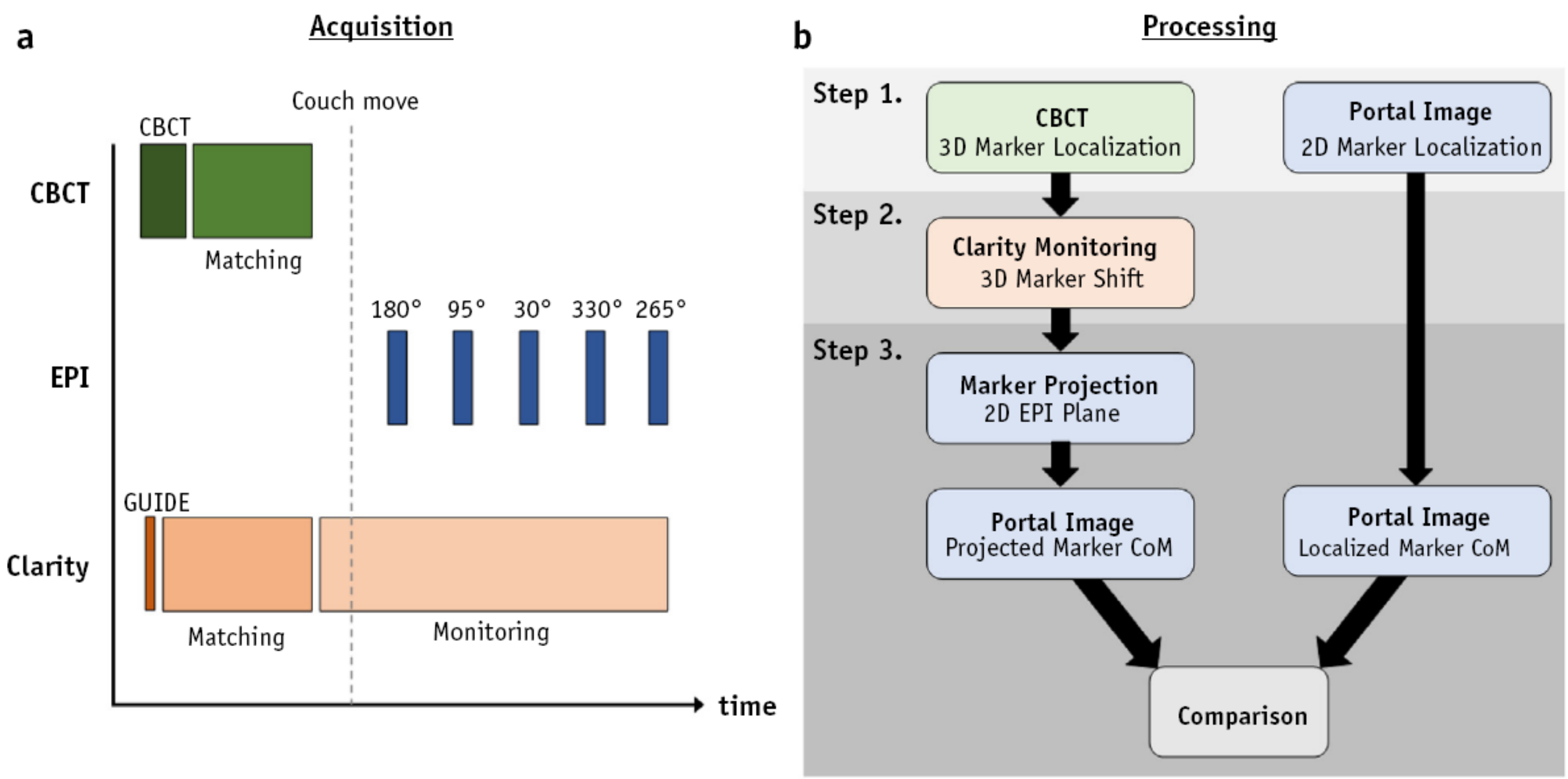

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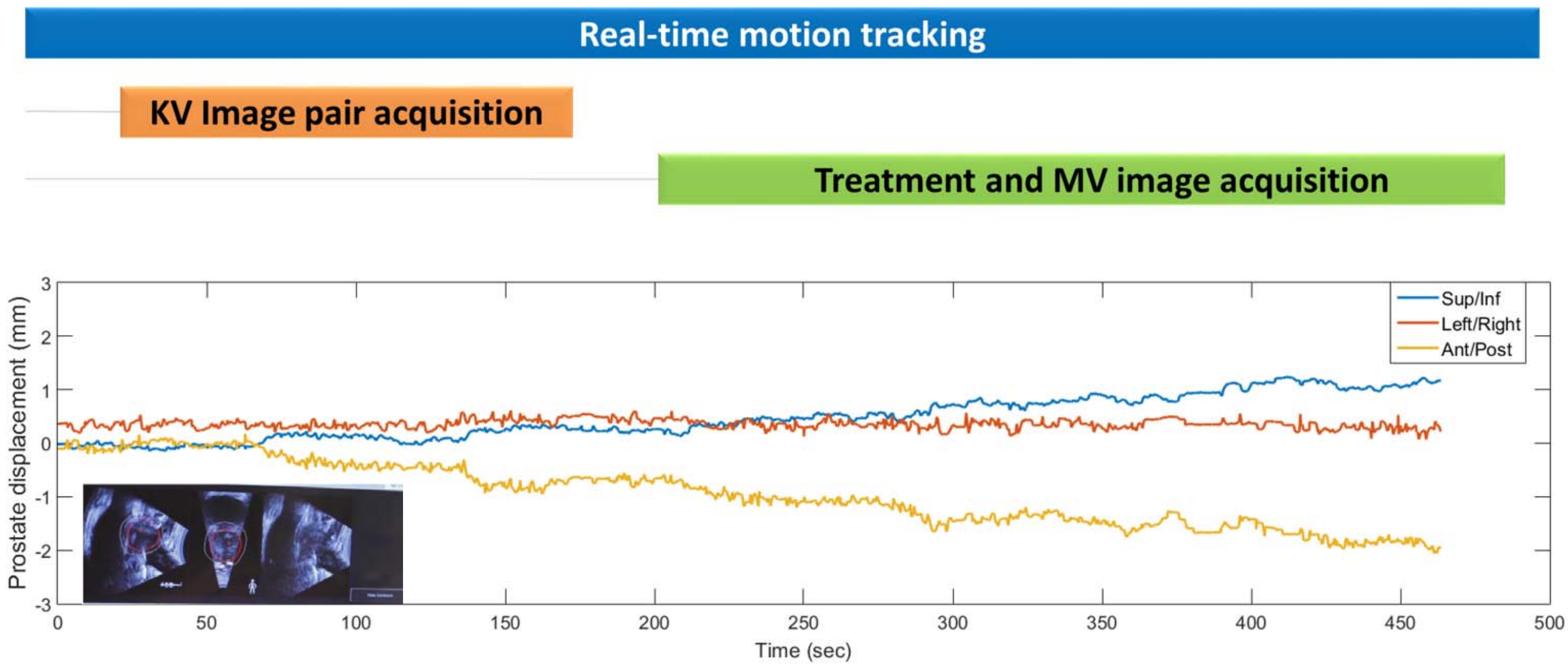

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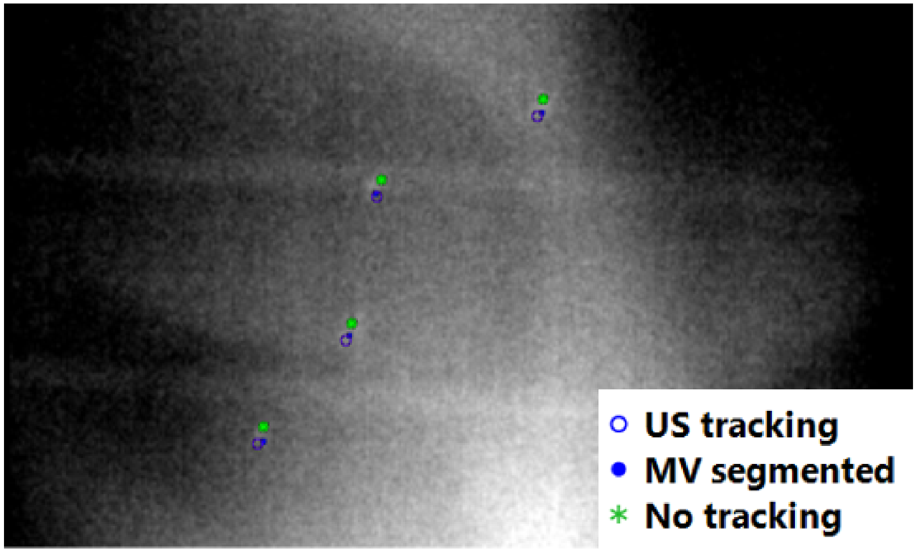
3D TPUS IGRT tracking: how good is it?

Experimental design validation

A

B



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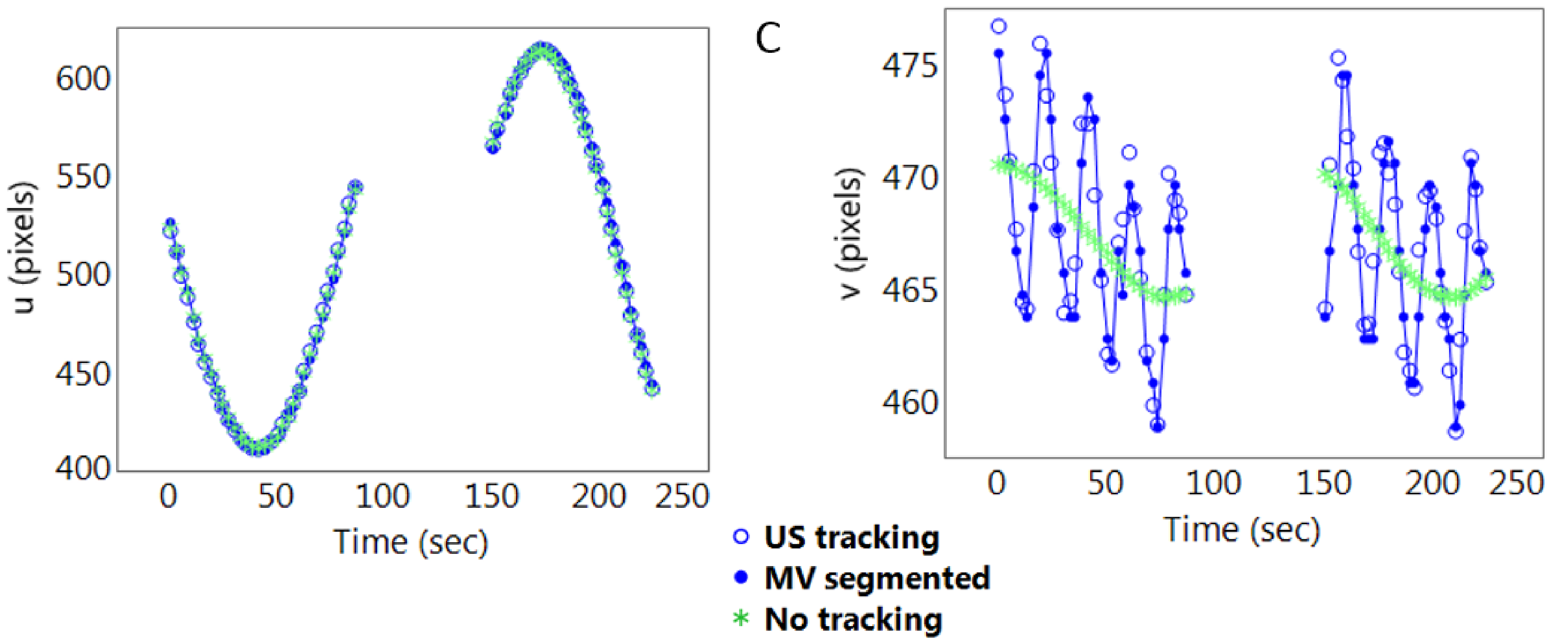

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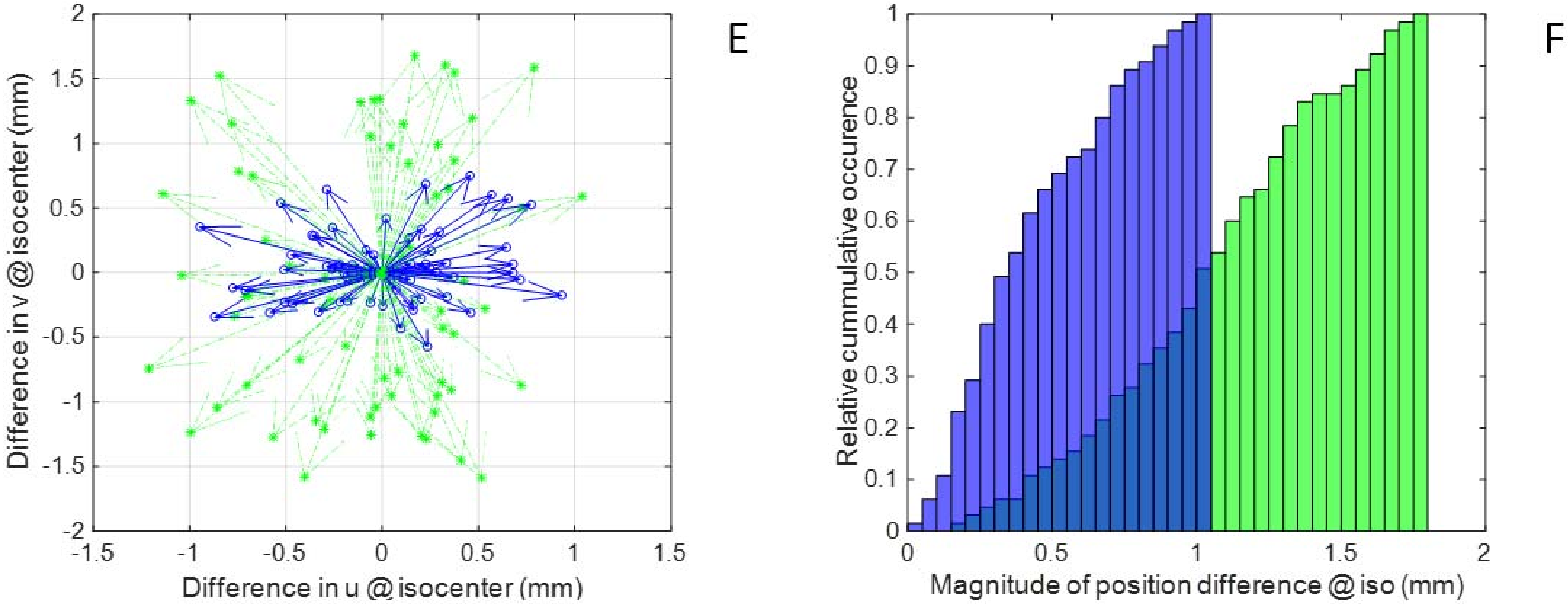
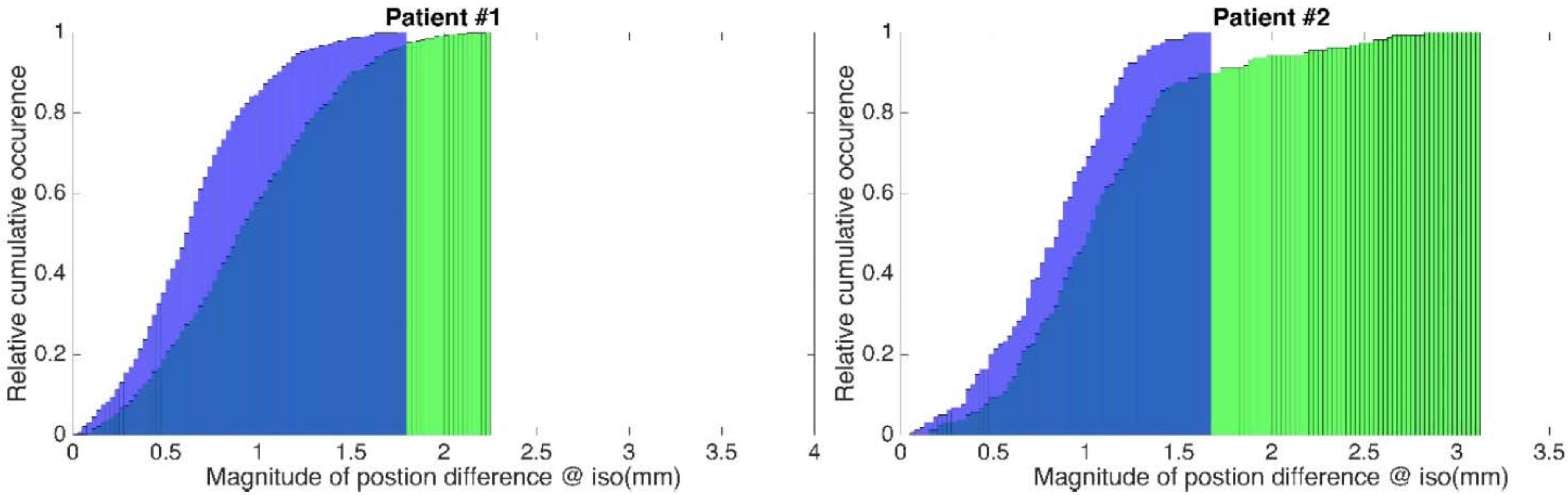


Experimental design validation: 3D TPUS tracking reduces position uncertainty to within ~ 1mm in phantom

Han, B., et al., Radiat Oncol, 2018. 13(1): p. 151.

3D TPUS IGRT tracking: how good is it?



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3D TPUS IGRT tracking: how good is it?

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Magnitudes of the position differences (scaled at isocenter) between mean predicted and mean actual (MV segmented) fiducial positions for individual patients. Predicted positions are calculated with and without ultrasound tracking.

Magnitude of position differences @ iso (mm)				
	Maximum		**At 95% relative cumulative occurrence**	
Patient #	*Without tracking*	*With tracking*	*Without tracking*	*With tracking*
1	2.3	1.8	1.7	1.2
2	3.1	1.7	2.2	1.3
3	1.3	1.3	1.1	1.0
4	3.9	3.3	2.4	2.1
5	1.9	1.5	1.5	1.2

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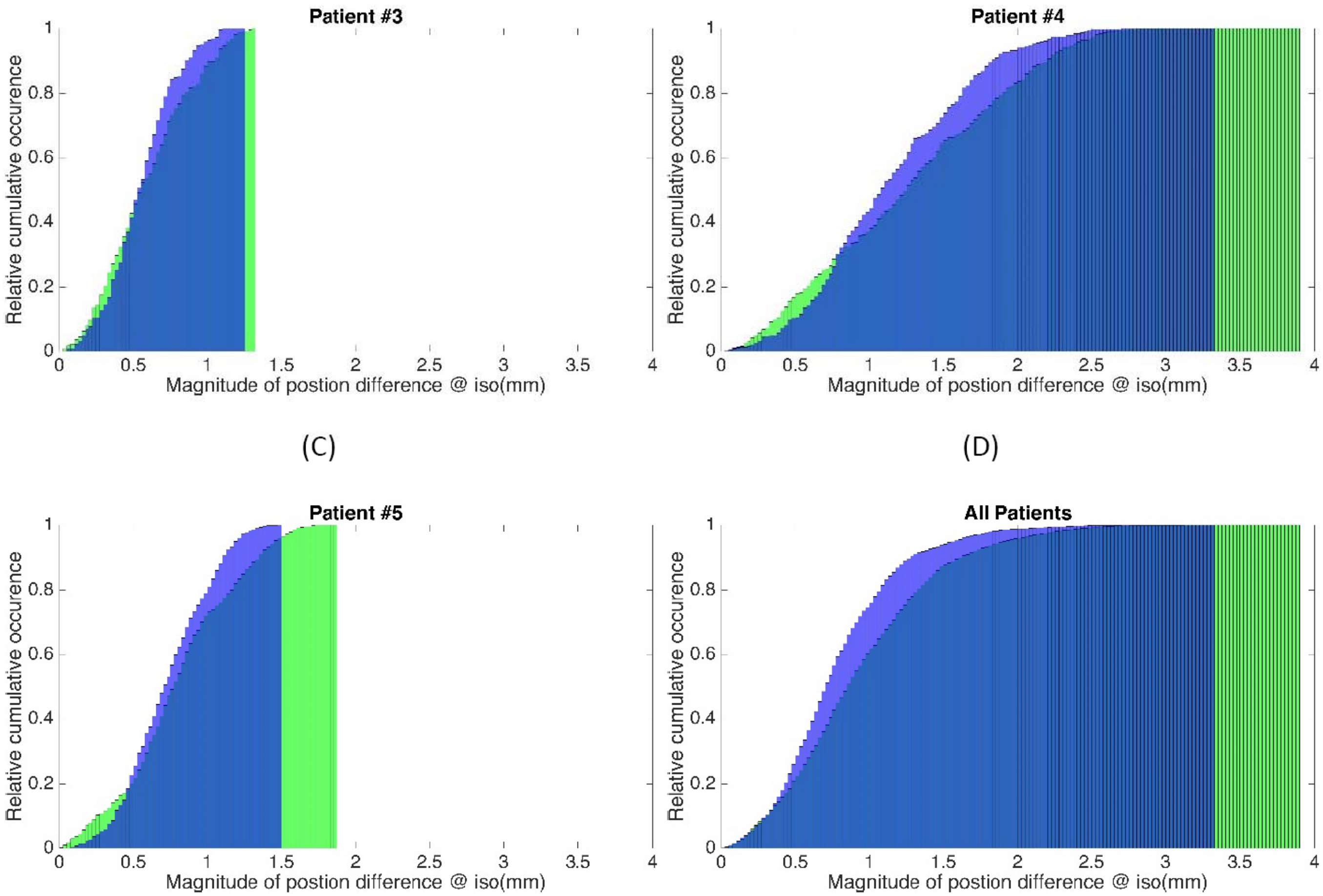

Maximum localization error reduced by 20% on average.

Han, B., et al., Radiat Oncol, 2018. 13(1): p. 151.

3D TPUS IGRT tracking: how good is it?

Limit of agreement	u-Axis, mm	v-Axis, mm	2D magnitude, mm
25%	−0.2 to 0.3	−0.2 to 0.4	0.6
50%	−0.5 to 0.6	−0.5 to 0.7	1.0
75%	−0.9 to 1.0	−1.1 to 1.1	1.5
95%	−2.0 to 2.1	−2.5 to 1.9	2.6
$\lvert\tilde{E}\rvert$	0.6	0.6	1.0

Grimwood, A., et al., Int J Radiat Oncol Biol Phys, 2018. 102(4): p. 912-921.

Summary

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- Trans-perineal ultrasound offers non-ionizing near real time volumetric imaging conceptually attractive for prostate intra- and inter-fractional image guidance.

- Current TPUS accuracy appears insufficient for demanding indications such as prostate SBRT (aka SABR).

  - User-variability in acquisition and interpretation a dominant factor in performance
  - Need for approaches to mitigate/eliminate this source of uncertainty

- TPUS intra-fractional tracking can flag target deviations exceeding ~2-3 mm, but effort/benefit analysis perhaps only justifiable for prostate SBRT scenarios.