Stellenwert der online adaptiven RT bei ultra-hypofraktionierter SBRT der Prostata

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Graz
06.02.26

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UNIVERSITÄTSMEDIZIN
MANNHEIM

Medizinische Fakultät Mannheim
der Universität Heidelberg

Universitätsklinikum Mannheim

Universitätsklinikum Mannheim

Klinik für Strahlentherapie:

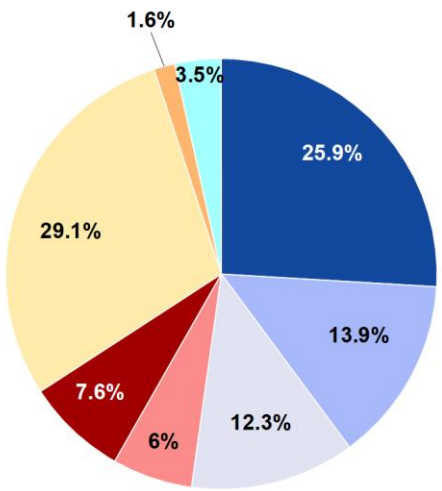
- 2 x Elekta Versa HD (mit Gating & SGRT)
- 1 x Elekta Synergy
- 1 x Elekta Gamma Knife
- 2 x Elekta Synergy in 2 Privatpraxen
- 1 x Varian Ethos (mit SGRT)

Ethos Timeline:

- Sept & Okt 2023: Installation & Schulungen
- 12.12.2023: RT des ersten uHF-Patienten
- Juli 2024: Upgrade auf Ethos 2.0

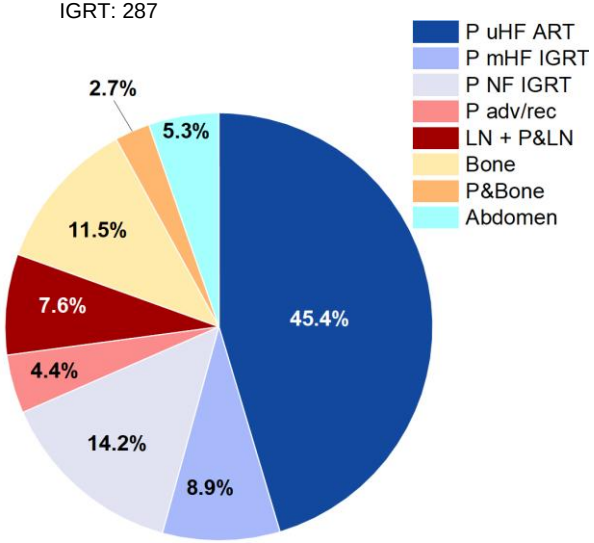
Stand Jan 25

insgesamt: 316 Patienten
ART (uHF P + andere Sites): 82+13
IGRT: 221



Stand Jan 26

insgesamt: 575 Patienten
ART (uHF P + andere Sites): 256 +32
IGRT: 287



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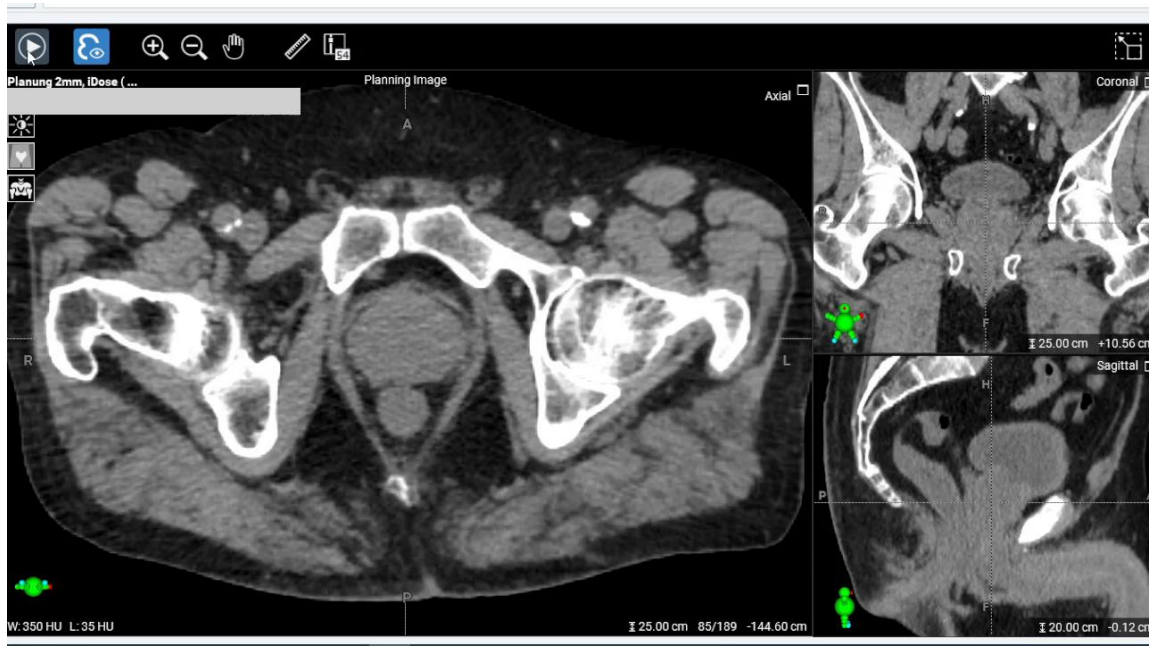
Online adaptive Strahlentherapie (oART)

Vorteile ? **Kompensation von Bewegung, Organfüllung & Deformation**



Dona Lemus OM, et al.: *Adaptive Radiotherapy: Next-Generation Radiotherapy*. Cancers (Basel). 2024

	MRI	CBCT	PET
Current systems	Elekta Unity 1.5 T MRI with a 7MV FFF LINAC ViewRay MRIdian (legacy system) 6MV FFF 0.35 T MRI	Varian Ethos 6MV FFF	RefleXion X1 6MV FFF
ART workflow	Unity: Adapt to position (ATP) and adapt to shape (ATS). MRIdian: Choice between scheduled vs. adaptive plans.	Choice between scheduled vs. adaptive plans.	Offline ART feasible; online ART under development.
Strengths	• Superior soft-tissue contrast; • No radiation dose, can therefore provide continuous real-time monitoring during treatment; • Functional and metabolic imaging.	• Faster imaging speed, especially with HyperSight™; • High throughput; • Cheaper and more accessible than the other two modalities; • Planning directly on CBCT with HyperSight™.	• Metabolic and functional imaging; • On-board kVCT provides good imaging quality; • Real-time tracking; • Multi-target delivery.
Limitations	• Expensive; • Longer imaging time and slow throughput; • Need electron density for planning (MRIdian: DIR; Unity: bulk electron density); • MR safety compatibility; • Technical interference with LINAC.	• Limited soft-tissue contrast; • Radiation dose; • No functional imaging.	• Expensive; • Longer imaging time; • Radiation dose; • Requires management of radiotracers; • Need to combine with CT for anatomy and planning; • Technical interference with LINAC.
Key clinical sites	• Abdominal; • Pelvic.	• Pelvic; • Head and neck; • Breast; • Lung.	• Lung; • Bone.

Online adaptive Strahlentherapie (oART)

Umsetzung?

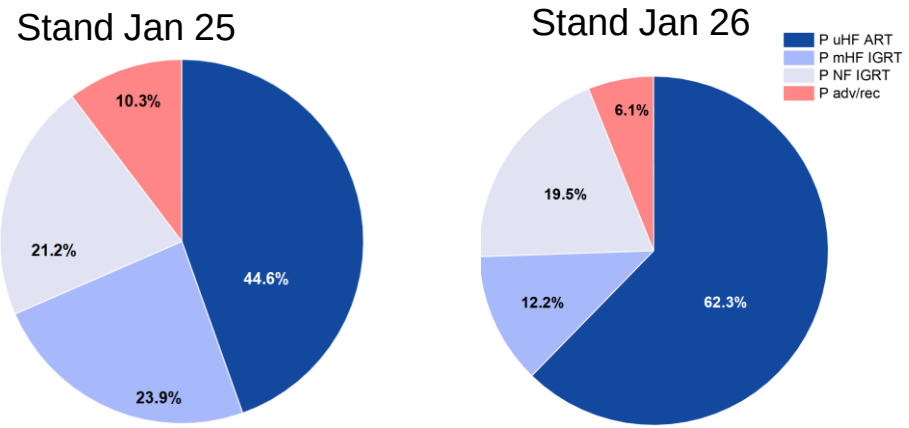
IGRT

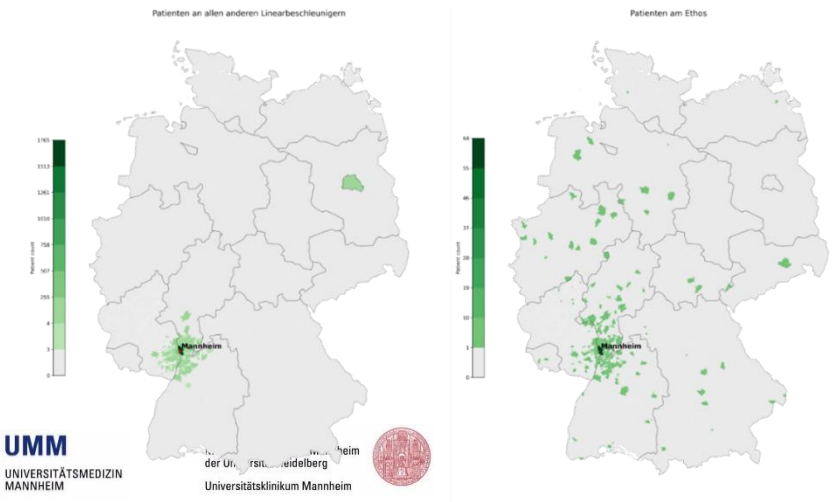
1. Einführung / Organisation der oART
2. Tägliche Bildqualität
3. Segmentierung
4. Dosisoptimierung
5. Organbewegungen

1.1 IGRT vs. oART

<u>P Ca Fraktionierungen:</u>

- Normo- (71.4Gy à 2.38Gy) vs. hypo- (60Gy à 3Gy) vs. ultra-hypofraktioniert (40Gy à 8Gy)





	NF + mHF (IGRT)	uHF (oART)
Parameter	**2.0 (6 Monate)**	**2.0 (6 Monate)**
Patienten	35	28
MU	1704 ± 245,4	3600,1 ± 294,4
Beam-on Time (min)	3,55 ± 0,45	**7,0 ± 1,0**
Mobius Gamma (%)	98,3 ± 1,2	99,8 ± 0,2
Veriqa Gamma (%)	99,5 ± 0,4	99,94 ± 0,13
Planungs-versuch	6,3 ± 2,9	4,5 ± 3,9 & Modifikationen

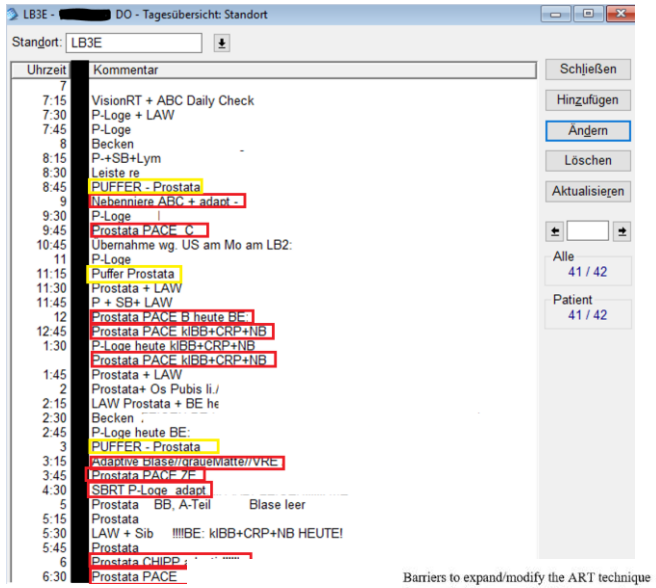
1.2 Organisation der klinischen Routine

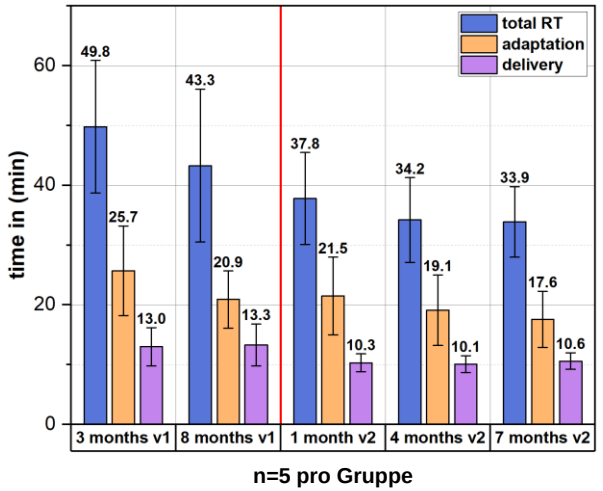
Herausforderungen

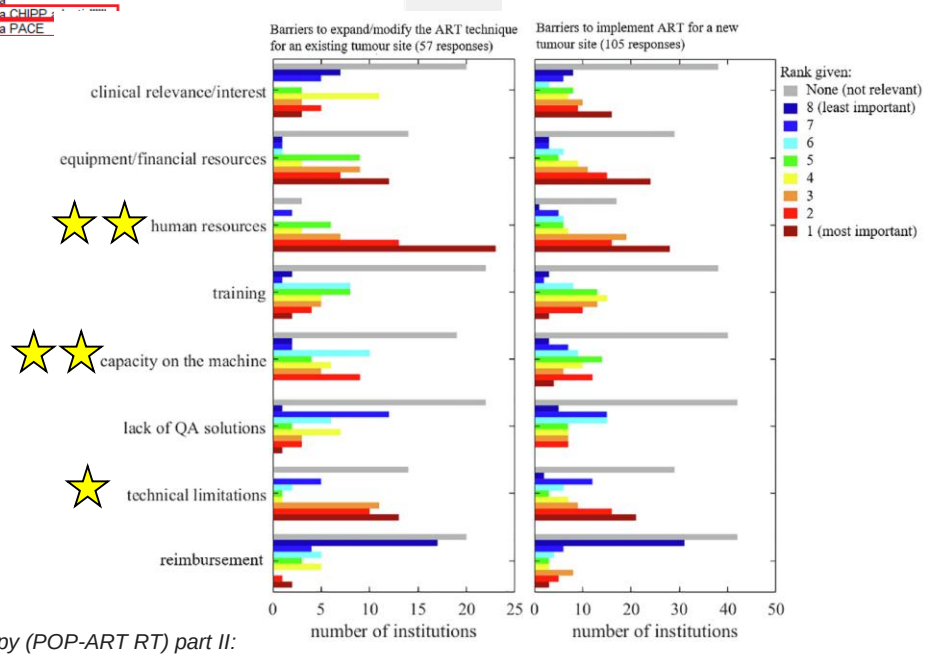
- Aufwendigere Terminierung & Pufferzeiten (ART 45min vs. IGRT 15min)
- Vorbereitung & Nachsorge der Patienten
- Schulungen von dedizierten Abläufen (KI)

(vs. IGRT)

- Erhöhter Personalaufwand (MTRs, Ärtze, MPEs) & Verfügbarkeit für oART
- Ausfallkonzept
- Wechselndes Personal & Interobserver Variabilität pro Patient (oART Qualität?)
- **mehr Aufwand vs. mehr Möglichkeiten**







Bertholet J, et al.: *Patterns of practice for adaptive and real-time radiation therapy (POP-ART RT) part II: Offline and online plan adaption for interfractional changes*. Radiother Oncol. (2020)

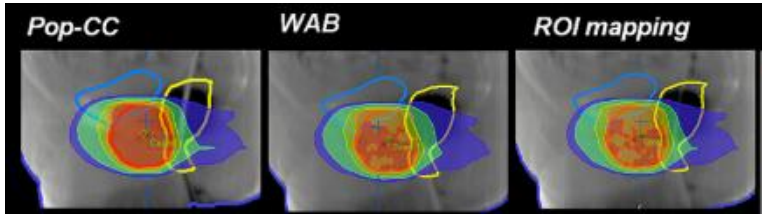
2.1 Einfluss des synthetischen CBCT / MRT

- “HU-ED-override” Ansätze
- Korrekturalgorithmen für Streuung
- Registrierungsmethoden zum Planungs CT

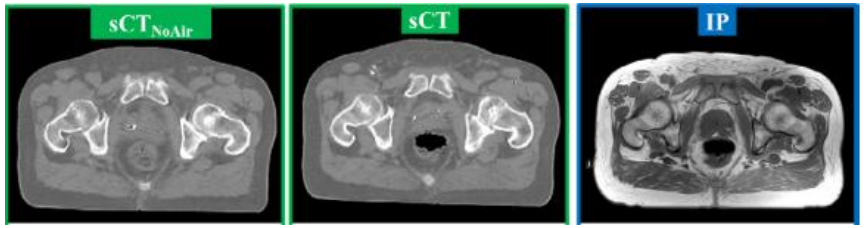
⇒ Verbesserung durch KI

⇒ reale Anatomie? Einfluss auf Segmentation & Dosis

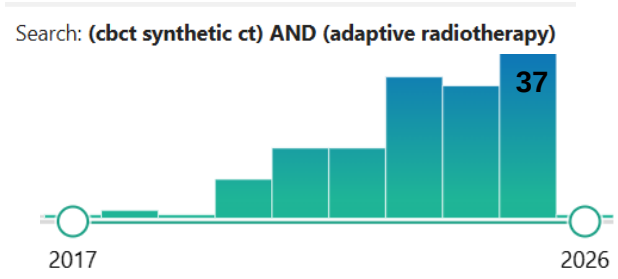
⇒ **tägliche Anpassung vs. Unsicherheit**

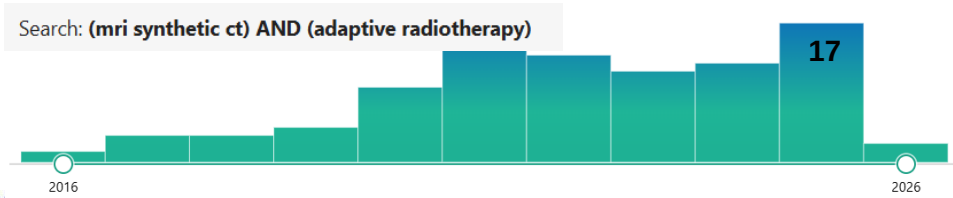


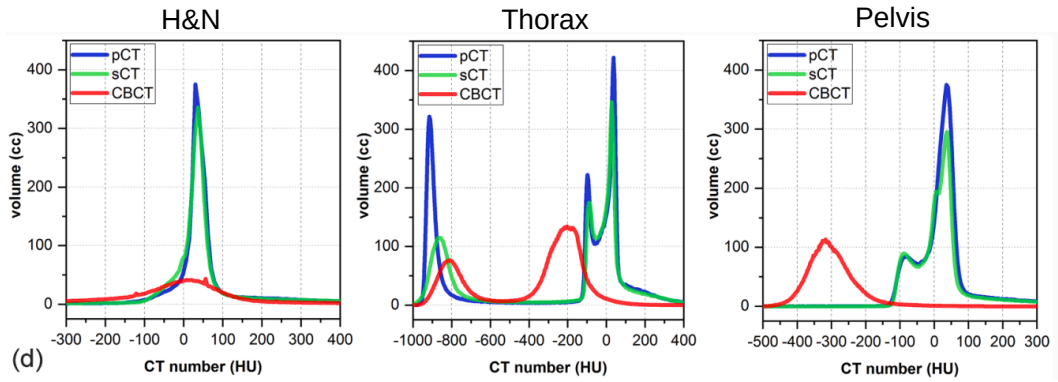
Fotina et al.: *Feasibility of CBCT-based dose calculation: Comparative analysis of HU adjustment techniques*, Radiother. Onc. (2012)



Maspero et al.: *Dose evaluation of fast synthetic-CT generation using a generative adversarial network for general pelvis MR-only radiotherapy*, Phys.Med.Biol. (2018)





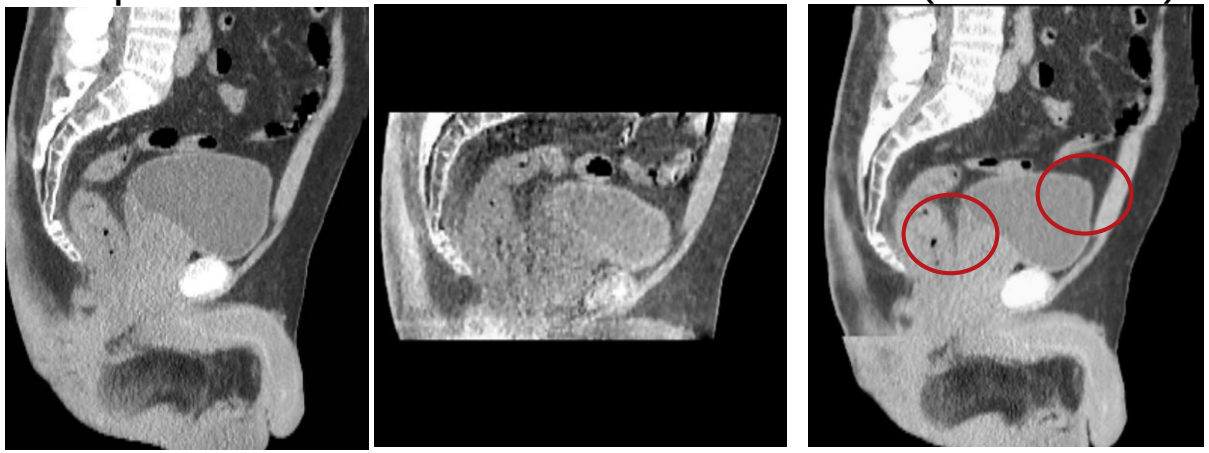


Eckl et al.: *Evaluation of a cycle-generative adversarial network-based cone-beam CT to synthetic CT conversion algorithm for adaptive radiation therapy*, Physica Medica (2020)

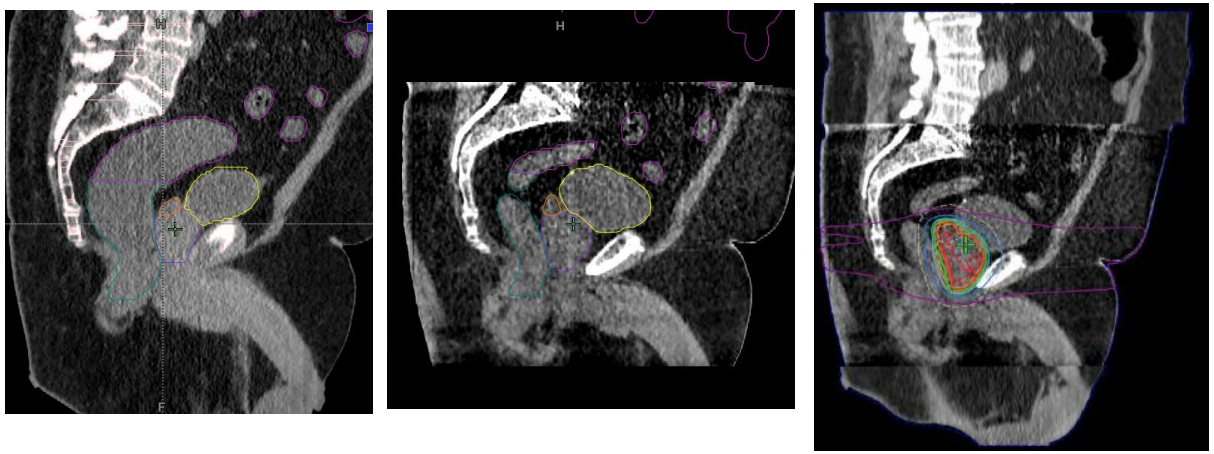
2.2 sCT vs. natives CBCT

pCT | CBCT | sCT (DIR-based)

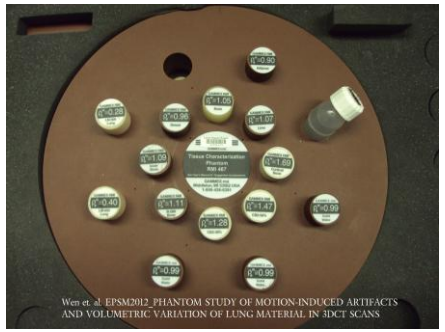
Ethos v1.01

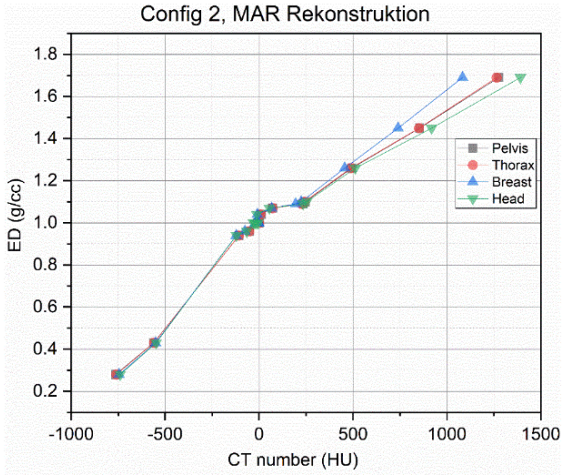


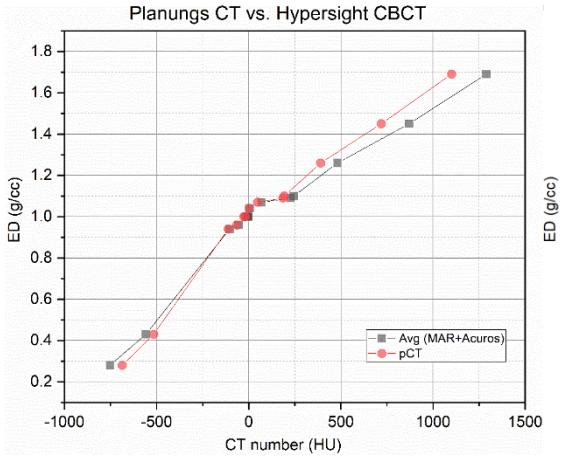
Ethos v2.0

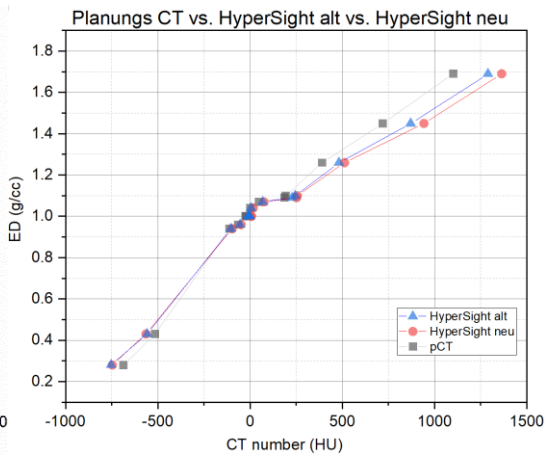


HyperSight CBCT (2023)









Ethos 2.0:

⇒ verbessertes sCT („CBCT anatomy priorization“)

⇒ **Dosisberechnung auf CBCT** für Acuros/MAR Rekonstruktion

⇒ Hinterlegung verschiedener Kalkurven

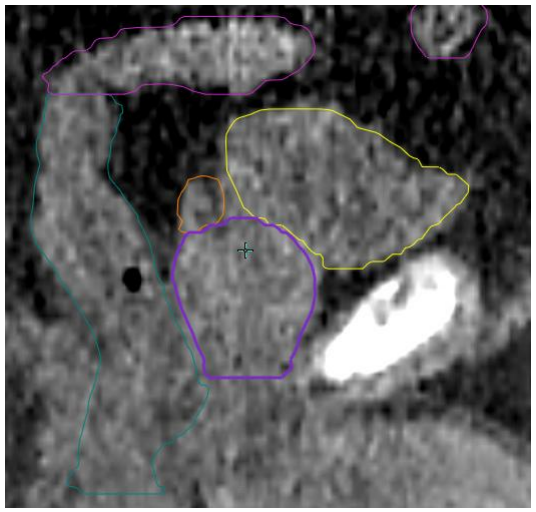
⇒ engmaschigere QA-Frequenz?

3.1 (Auto) Segmentierung

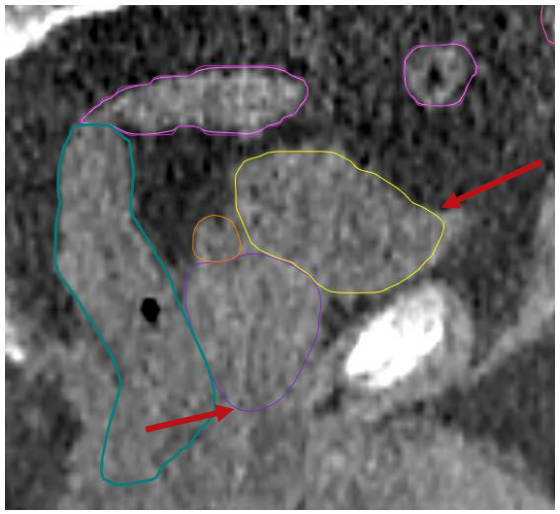
Zeit für Konturierung eines RT Struct : 1.5 min

Blase
Sigma
Femur links
Femur rechts
Prostata
Rectum
Samenblasen
TEP
Dünndarm

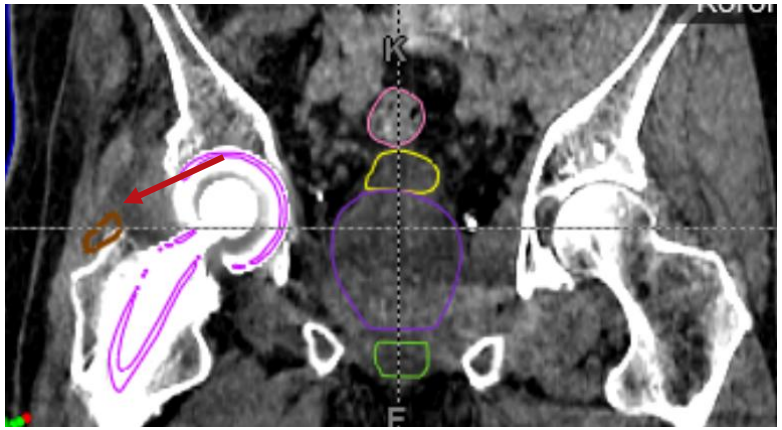
manuell

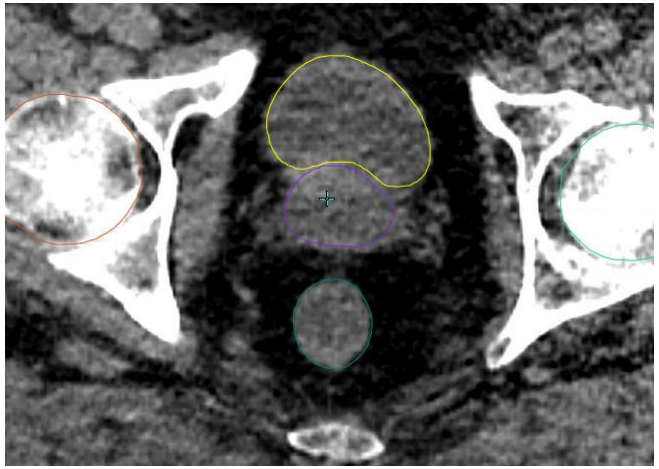


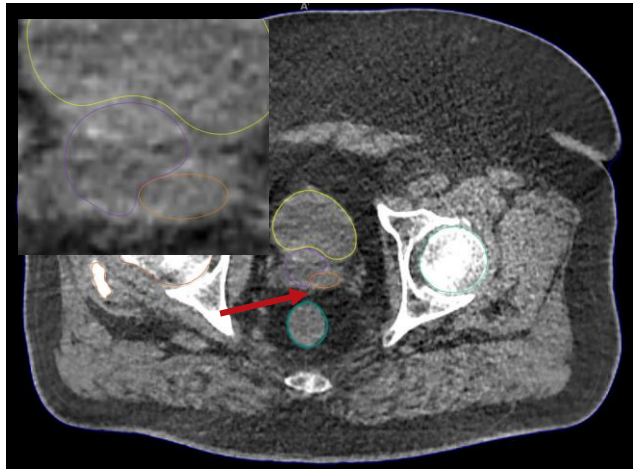
automatisch



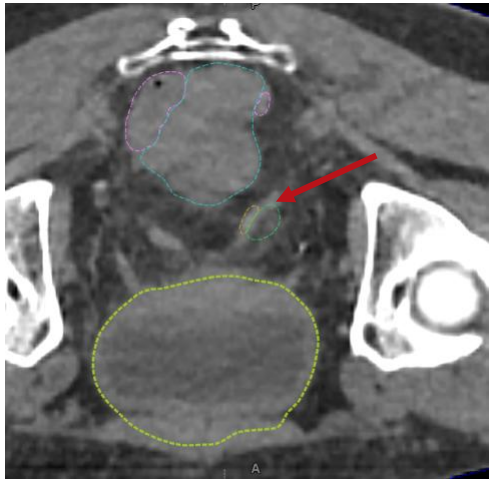
einseitige TEP







Bauchlage Pelvis



3.2 Segmentierung & Zeit

Okt 24 – Jan 25
16 Patienten
80 ART Fraktionen

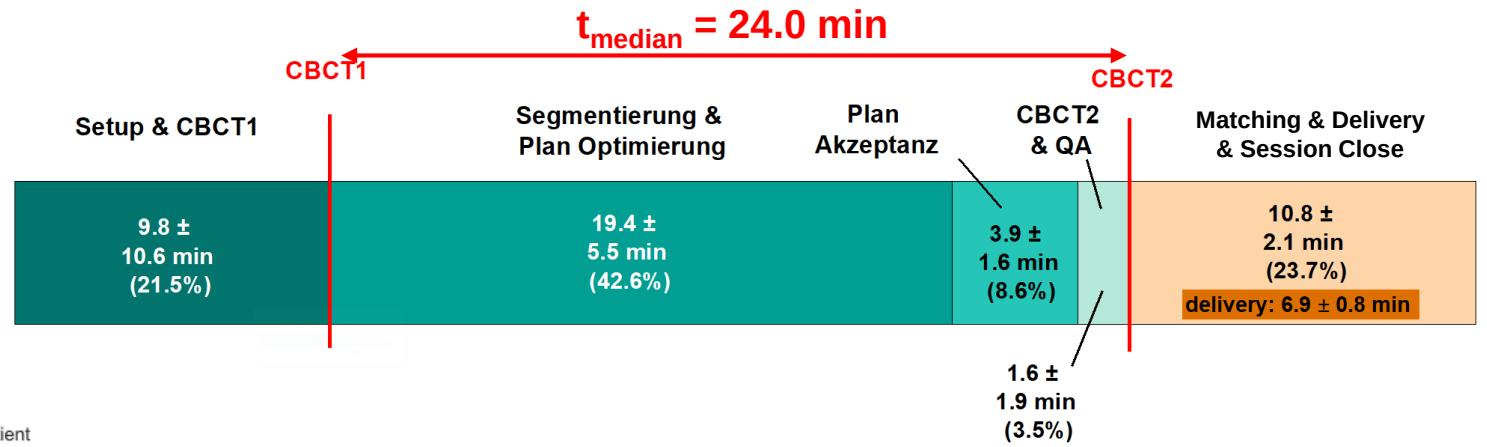


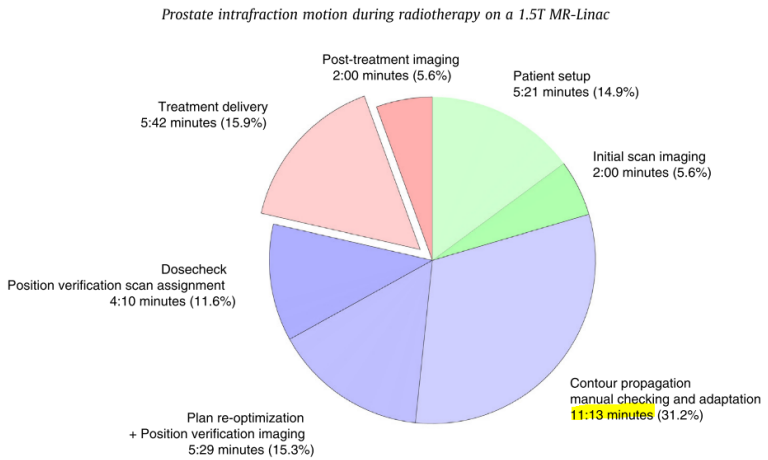
TABLE 4 Timing data for retrospective and clinical patient fractions

Treatment site	Retrospective data Adaptive time (average ± SD) (mm:ss)	Clinical data Adaptive time (average ± SD) (mm:ss)
Intact prostate	15:21 ± 03:18	33:57 ± 05:13
Intact prostate and nodes	19:30 ± 04:06	34:12 ± 06:23
Prostate bed and nodes	21:20 ± 03:55	34:17 ± 07:23
All sites	19:11 ± 04:29	34:11 ± 06:34

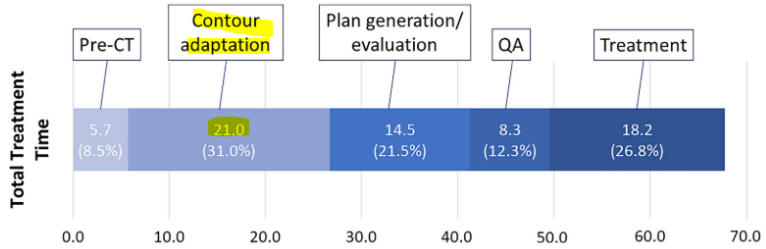
Byrne et al. (2025): *Varian ethos online adaptive radiotherapy for prostate cancer: Early results of contouring accuracy, treatment plan quality, and treatment time*, J Appl Clin Med Phys (2022)

	Contouring/ Adaptation [min]	QA Time [min]	Beam-on Time [min]	Interval Between CBCT1–CBCT2 [min]	Total Treatment Time [min]
Mean	12:11	05:27	05:22	17:38	30:17
Std. Dev.	05:14	01:23	00:44	05:02	05:49
Minimum	04:09	03:00	03:58	11:00	22:37
Maximum	24:51	08:42	06:39	28:35	43:07
25th percentile	07:59	04:35	04:43	16:00	25:07
Median	10:37	05:00	05:29	13:30	30:31
75th percentile	16:20	06:04	05:56	21:49	33:00

Wurschi G, et al.: *CBCT-Based Online Adaptive, Ultra-Hypofractionated Radiotherapy for Prostate Cancer: First Clinical Experiences.* Medicina (Kaunas). 2025



de Muinck Keizer DM, et al. *Prostate intrafraction motion during the preparation and delivery of MR-guided radiotherapy sessions on a 1.5T MR-Linac. Radiother Oncol.* 2020



Brand et al.: *First-in-Men Online Adaptive Robotic Stereotactic Body Radiation Therapy: Toward Ultrahypofractionation for High-Risk Prostate Cancer Patients*. Adv Radiat Oncol (2025)

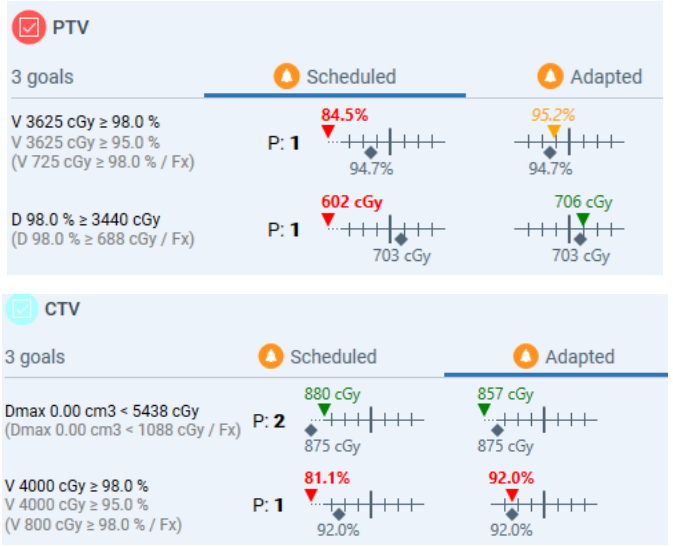
zeitlicher Nachteil durch oART vs. Verbesserung durch KI

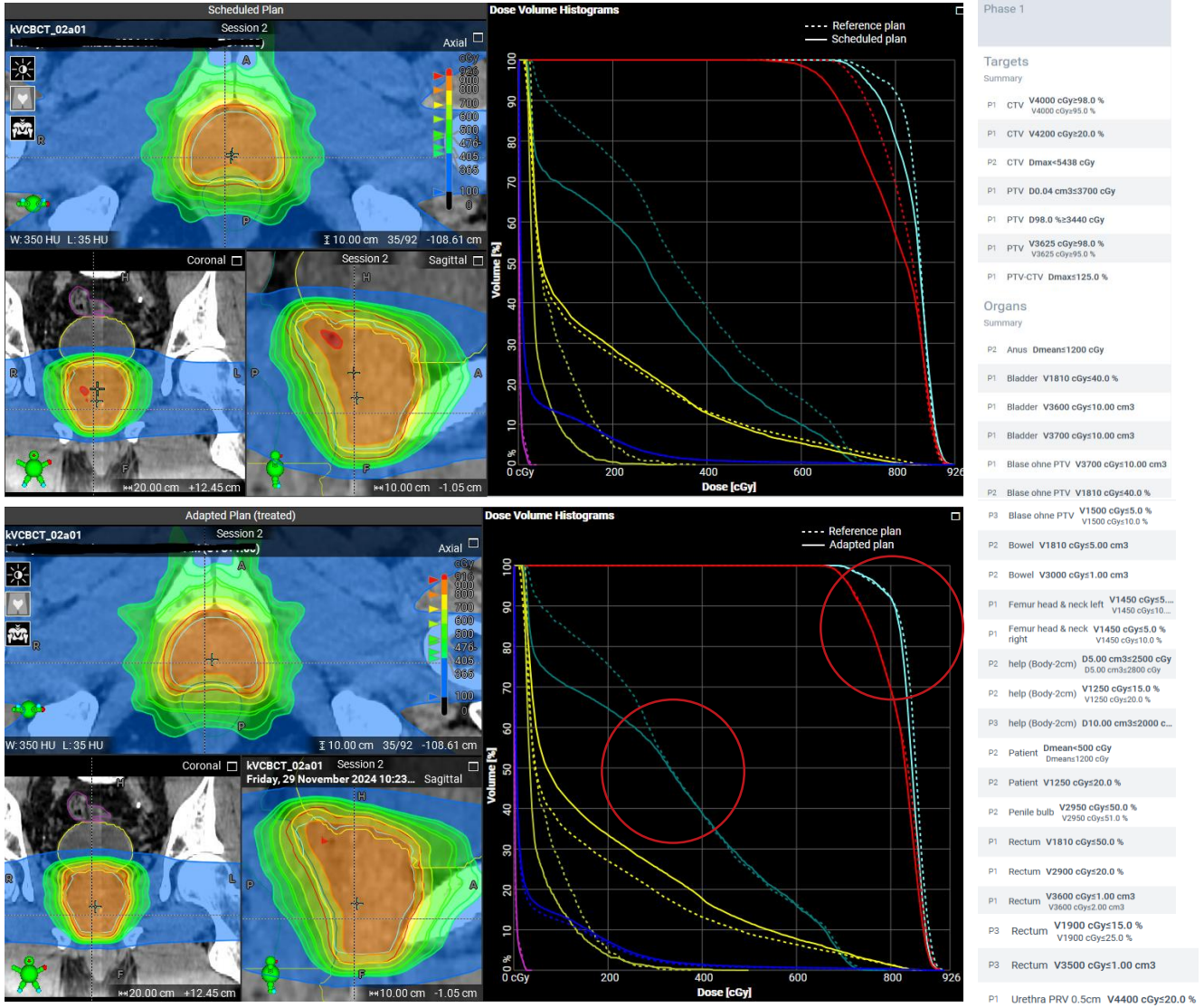
Eckl et al. : *Analysis of Online Adaptive Treatment Quality in a Cone-Beam-CT Based Workflow for Ultra-Hypofractionated Radiation Therapy of Prostate Cancer*, Physics and Imaging in Radiation Oncology (2025)

4.1 Tägliche Dosisoptimierung

Auswahl zwischen 2 Behandlungsarten:

- SCH: rekalkuliert auf CBCT & IGRT Tischverschiebung
- ADP: re-optimiert auf CBCT (gleiche Strahlgeometrie & Constraints)





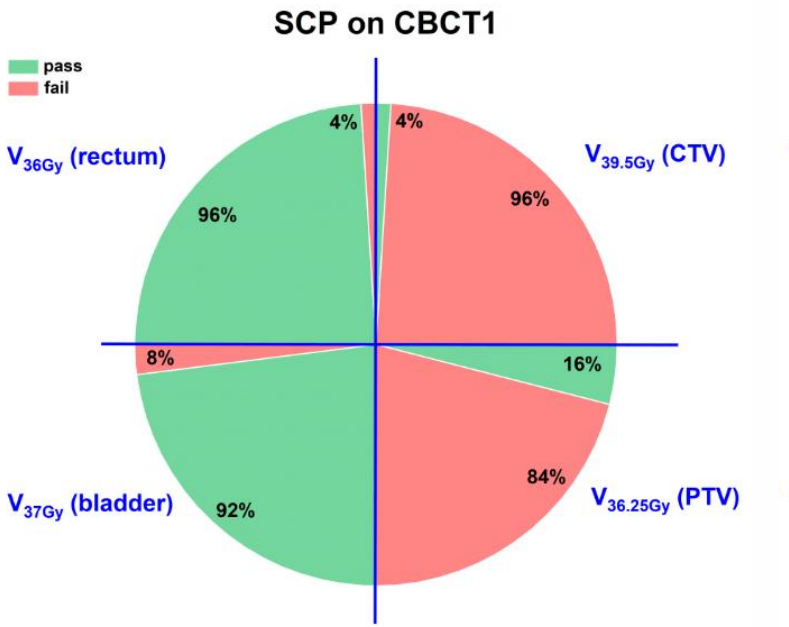
Vorteil durch oART : optimale Anpassung der täglichen Dosis (max. Referenzzustand)

4.2 CBCT oART: Dosisvorteil vs. Zeit

5 Patienten

25 ART Fraktionen

80 Pläne



35.1 min

Lange oART : Verlust des dosimetrischen Vorteils!

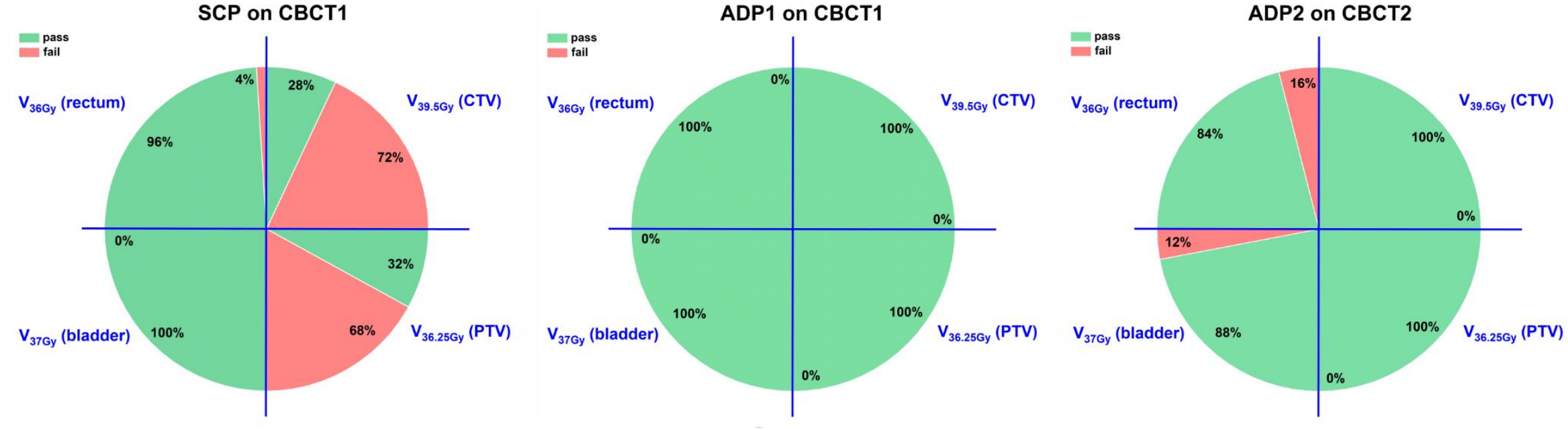
Eckl et al. (2025): *The impact of adaptation time on treatment quality in CBCT-based ultra-hypofractionated adaptive radiation therapy for prostate cancer*, ESTRO poster #E25-1924

4.2 CBCT oART: Dosisvorteil vs. Zeit

5 weitere Patienten

25 ART Fraktionen

80 Pläne



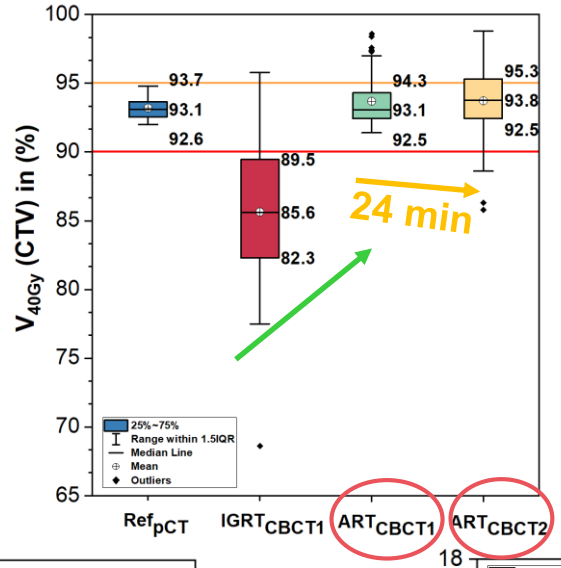
23.3 min

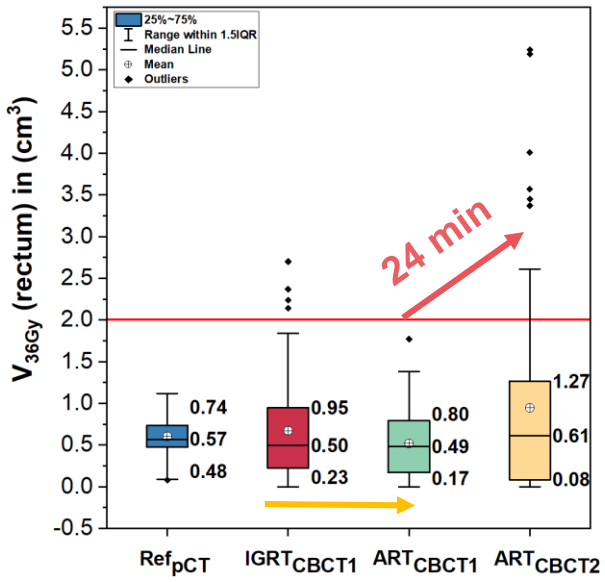
Erfahrung, Schnelligkeit & Pragmatismus

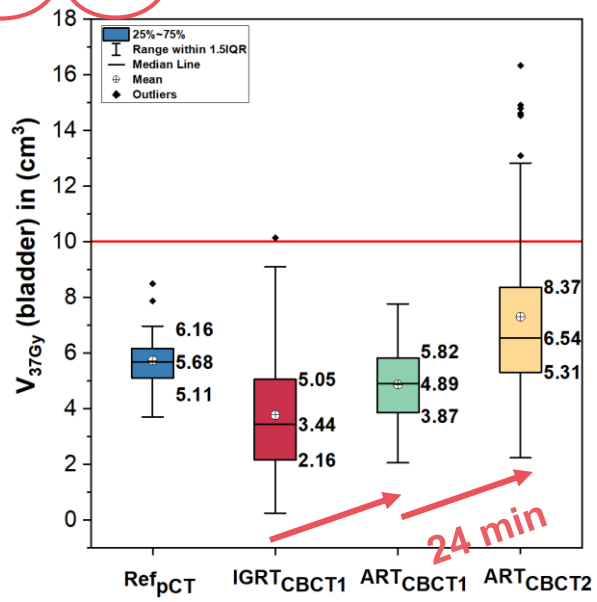
Eckl et al. (2025): *The impact of adaptation time on treatment quality in CBCT-based ultra-hypofractionated adaptive radiation therapy for prostate cancer*, ESTRO poster #E25-1924

4.2 CBCT oART: Dosisvorteil vs. Zeit

16 Patienten
80 ART Fraktionen
256 Pläne
ART Zeit: 24 min







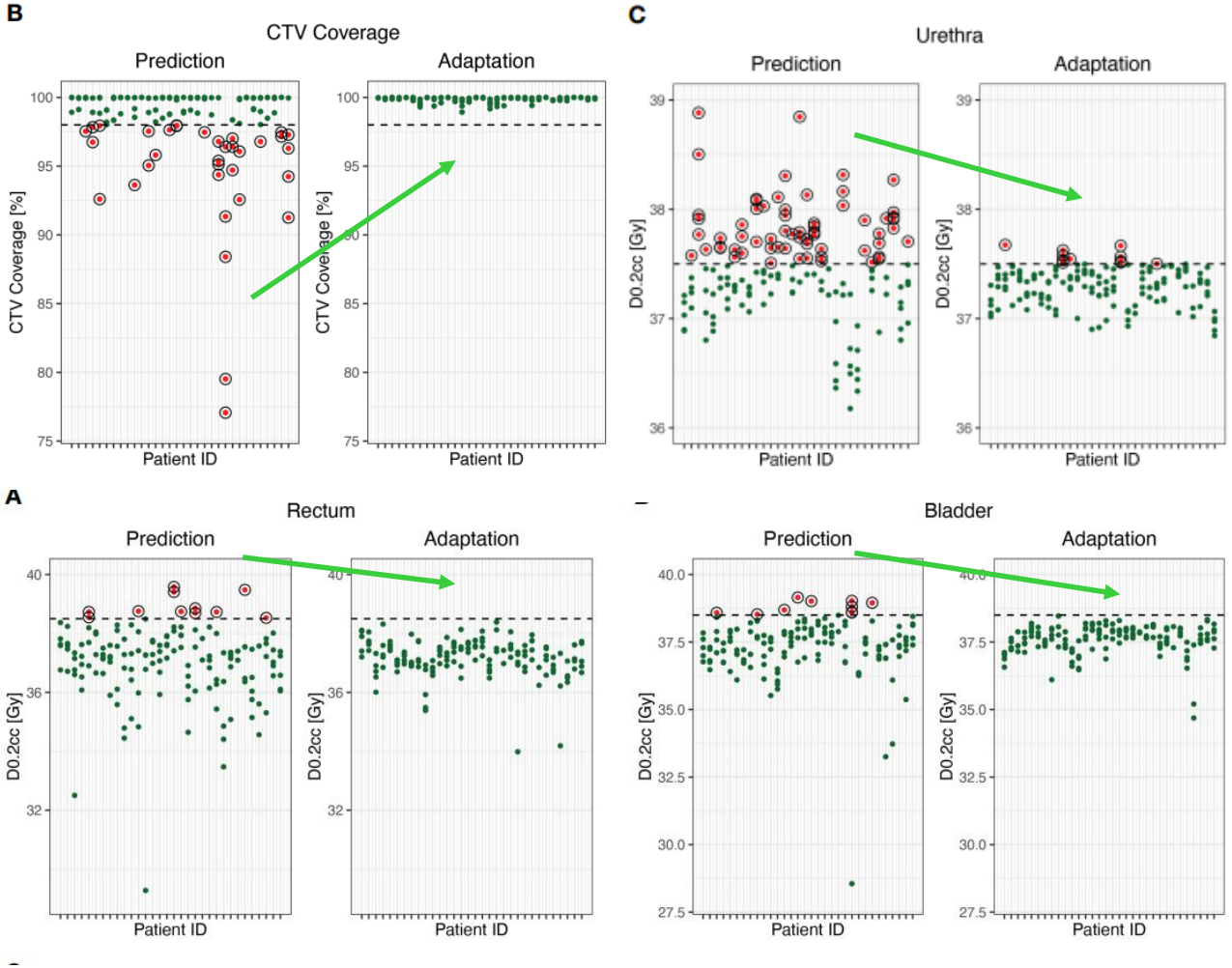
- **oART: ↑ Zielvolumen-Abdeckung vs. IGRT.**
- OAR profitieren durch oART nur bedingt.
- Lange Adaptionszeiten : ↓Planqualität auf CBCT2 .
- Wiederherstellung der Ref-Dosisqualität mit **gleichen** Constraints ausreichend
- Hauptursachen: Luft im Rektum, pelvine Muskelbewegung und Blasenfüllung.

Eckl et al. : *Analysis of Online Adaptive Treatment Quality in a Cone-Beam-CT Based Workflow for Ultra-Hypofractionated Radiation Therapy of Prostate Cancer*, Physics and Imaging in Radiation Oncology (2025)

4.3 MRT oART: Dosisvorteil vs. Zeit

32 Patienten
SMILE trial (37.5Gy à 7.5Gy)

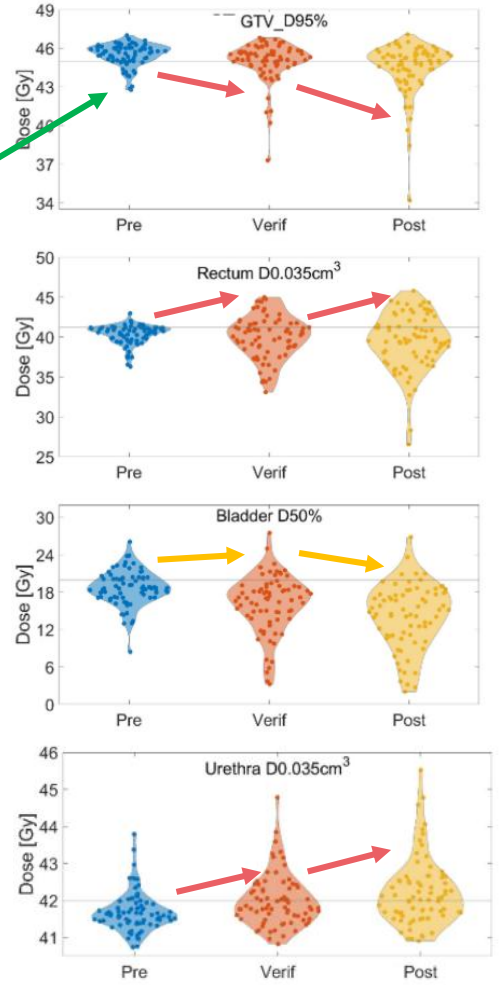
ART Zeit: 39 min



Fink CA et al.: *Dosimetric benefit of online treatment plan adaptation in stereotactic ultrahypofractionated MR-guided radiotherapy for localized prostate cancer*. Front Oncol. 2024

15 Patienten
uHF focal Boost (40/45Gy à 8/9Gy)

t (pre-post) : 54 min
t (pre-verif) : 35 min



- kein IGRT oder Ref Plan
- 2 zusätzliche Zeitpunkte: Verifikation & Post-RT

mehr Vorteile durch schnelle CBCT oART oder gar erweiterte IGRT?

Brennan VS et al.: *SBRT focal dose intensification using an MR-Linac adaptive planning for intermediate-risk prostate cancer: An analysis of the dosimetric impact of intra-fractional organ changes*. Radiother Oncol. 2023

4.4 Erweiterte IGRT vs. oART

Leeman JE, et al.: *Acute toxicity comparison of magnetic resonance-guided adaptive versus fiducial or computed tomography-guided non-adaptive prostate stereotactic body radiotherapy: A systematic review and meta-analysis.* Cancer. 2023

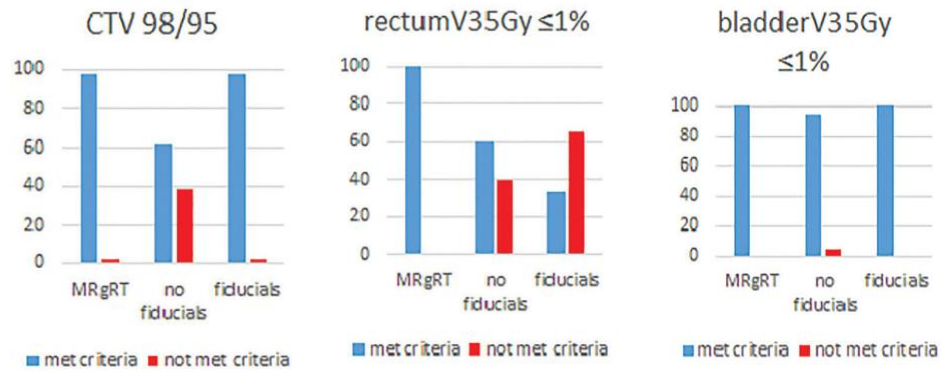
In this systematic review and meta-analysis combining data from 29 clinical trials including 2547 patients, it was found that the risk of short-term urinary side effects was reduced by 44% and the risk of short-term bowel side effects was reduced by 60% with MRg-A-SBRT compared to CT-SBRT.

M. L. Sandoval et al.: *Non-Adaptive MR-Guided Radiotherapy for Prostate SBRT: Less Time, Equal Results*. Journal of Clinical Medicine 2021

with an AUA score of 9 (2–22) at the third follow-up. We observed a statistically significant decrease in PSA between pre-treatment and at first follow-up ($p < 0.005$). The most common toxicity was grade 2 urethritis, managed in all cases by tamsulosin. One patient developed grade 2 tenesmus relieved by topical steroids. No cases of grade ≥ 3 toxicity were seen in our patient population. Conclusions: By avoiding the extra time required for plan adaptation, MRgRT without daily adaptation allows for successful prostate SBRT with manageable toxicity. We continue to reserve our limited adaptive treatment slots for preoperative pancreatic and ultra-central lung SBRT patients, which require time-intensive respiratory gating and adaptive planning.

Nicosia L, et al.: *Daily dosimetric variation between image-guided volumetric modulated arc radiotherapy and MR-guided daily adaptive radiotherapy for prostate cancer stereotactic body radiotherapy*. Acta Oncol. 2021

Results: MRgRT resulted in a significantly lower rate of constraints violation as compared to IGRT without fiducials, especially for rectum V28Gy, rectum V32Gy, rectum V35Gy, rectum Dmax, and bladder Dmax. IGRT with fiducials reported high accuracy levels, comparable to MRgRT. MRgRT and IGRT with fiducials reported no significant prostate CTV underdosage, while IGRT without fiducials was associated with occasional cases of prostate CTV under dosage.



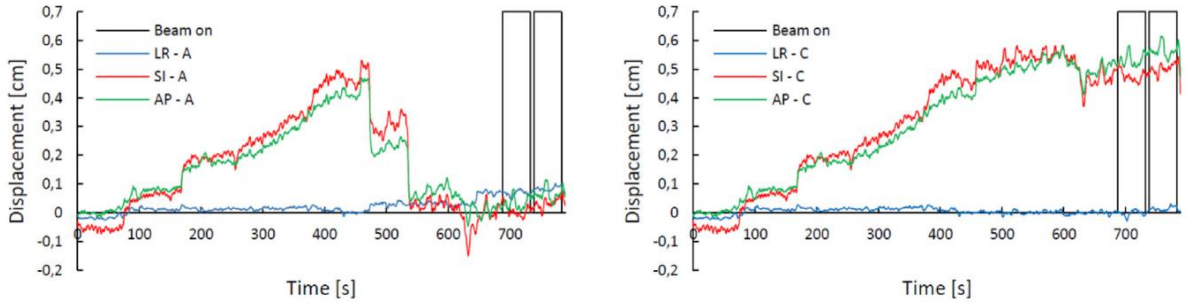
- **Vorteil für MRT oART :G2+ GU oder GI Toxizität**
- **Nachteil MRT oART: Aufwand & lange Behandlungszeit**
- **PROs für CBCT oART noch ausstehend**

5.1 Intrafraktionelles Monitoring

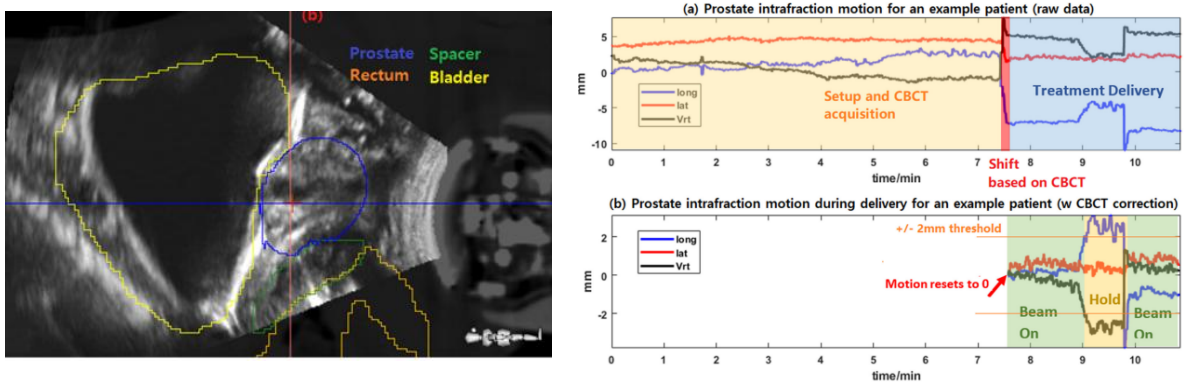
Table 3
Comparison between different studies employing various prostate monitoring devices.

Authors	# of patients	Monitoring system	Dose per fraction (Gy)	Treatment delivery time (min)	Average displacements (mm)	Average dosimetric results (planned VS delivered)		Notes
Faccenda et al. [32]	13	RayPilot	40 Gy/5 fr or 38 Gy/4 fr	2	LR: [−3.1,-0.8] SI: [−3.5,-1.9] AP: [−4.2,-3.7]	CTV D99%: −3% PTV D95%: −2.6 % Rectum D50%: −0.9 % Rectum D20%: −2% Bladder D40%: +3.2 % Bladder D0.035 cc: + 0.3 %		Gated and non-gated treatments; reported displacements for non-gated
Colvill et al. [34]	5	Kilovoltage intrafraction monitoring	80 Gy/40 fr	10	3D motion > 3 mm during 4.7 % of treatment time	CTV D99%: −19 % PTV D95%: −34 %		Gated and non-gated treatments. Fraction with the highest mean displacements considered
Vanhanen et al. [21]	22	Calypso	35 Gy/5 fr or 36.25 Gy/ 5 fr	10–13	Case A range: LR: [−2.7,1.8] SI: [−4.1,9.8] AP: [−2.2,3.1] Case B: LR: [−2.8,1.8] SI: [−4.2,11.8] AP: [−2.4,9.0]	Case A CTVD99%: −0.3 % ± 0.4 PTVD95%: −0.9 % ± 0.8 BladderV100%:9.5 % ± 63.9 RectumV100%:55.1 % ± 159.4	Case B CTVD99%: −0.4 % ± 0.6 PTVD95%: −1.2 % ± 1.5 BladderV100%:6.6 % ± 62.6 RectumV100%:81.3 % ± 265.9	Case A: gated treatments Case B: non-gated treatments
Kontaxis et al. [25]	5	MR-linac	62 Gy/20 fr	6	LR: 0.0 ± 0.2 SI: −0.3 ± 1.0 AP: 0.2 ± 0.9	CTV D99%: −2.1 % ± 2.9 % PTV D99%: −11 % ± 9.5 %, Bladder V60Gy: 1.6 % ± 2.3 % Rectum V60Gy: −0.2 % ± 2.2 %		Gated treatments
di Franco et al. (this study)	15	Clarity TP-US	36.25 Gy/ 5 fr	3–6	LR: −0.15 ± 0.98 SI: −0.21 ± 1.15 AP: −0.11 ± 1.57	CTV V100%: −4.8 % ± 2.6 % PTV V95%: −13.8 % ± 3.2 % Bladder D1cc:-1.8 Gy ± 2.0 Gy (−4.8 %) Rectum D1cc: − 2.1 Gy ± 3.2 Gy (−6.3 %)		Non-gated treatments

di Franco F. et al.: *Ultra-hypofractionated prostate cancer radiotherapy: Dosimetric impact of real-time intrafraction prostate motion and daily anatomical changes.* Physica Medica 2024



Vanhanen, A et al.: *Dosimetric effect of intrafraction motion and different localization strategies in prostate SBRT*. Physica Medica 2020



Guo B et al.: *Transperineal ultrasound is a good alternative for intra-fraction motion monitoring for prostate stereotactic body radiotherapy*. J Appl Clin Med Phys. 2023

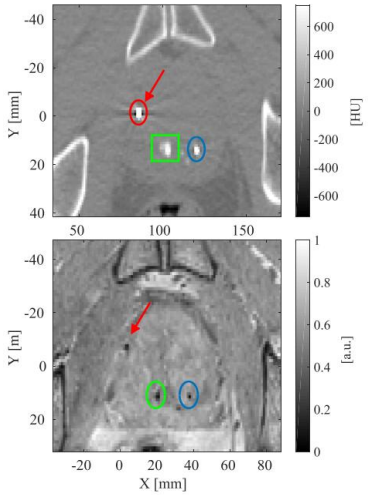
- invasive vs. non-invasive Methoden
- Patienten-Vorbereitung / Eignung => 5 Fraktionen
- Langzeiteffekte: IGRT vs. uHF SBRT
- Was passiert bei RT-Zeiten **über** 15min und **während** Beam On?

5.1 Monitoring & Immobilisierung

Fiducial Marker

CT

MRT



Maspero et al.: *Evaluation of an automatic MR-based gold fiducial marker localisation method for MR-only prostate radiotherapy. Phys. Med.Biol.* (2017)

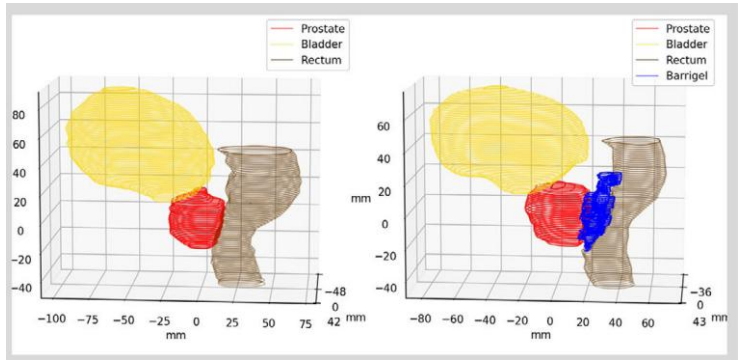
O'Neill AG et al: *Fiducial marker guided prostate radiotherapy: a review*. Br J Radiol. (2016)

FMs present a good surrogate for the position of the prostate and may reflect prostate gland motion or deformation. Changes in rectal and bladder volume, prostate deformation and SV motion are not detected by FM imaging alone.

Implantation of FMs is well tolerated, but surgical techniques and toxicity data require standardization. Development of FM implantation techniques that facilitate a reduction in the use of prophylactic antibiotic therapy should be considered in light of the global problem of multiresistant bacteria.

Schwieriger Ausgleich der OAR Deformation & Inflammationen => oART notwendig

Gel Spacer



Svatos M.: *Symmetry, separation, and stability: Physical properties for effective dosimetric space with a stabilized hyaluronic acid spacer.* Med Phys. (2024)

uHF Prostata SBRT

Mariados NF, T. et al. *Hyaluronic Acid Spacer for Hypofractionated Prostate Radiation Therapy: A Randomized Clinical Trial*. JAMA Oncol. (2023)

moderate HF, 12 Zentren, 201 Patienten

To our knowledge, this is the first randomized clinical trial evaluating the clinical efficacy of a rectal spacer for HFRT. This trial achieved the primary end point, in that more than 70% of patients in the spacer group achieved a 25% or greater reduction in rectal V54. This trial also achieved the secondary end point, in that the spacer group had reduced acute grade 2 or higher GI toxic effects (2.9%) compared with the control group (13.8%). Given that HFRT has been associated with greater acute grade 2 or higher GI toxic effects than CFRT,[7,12] rectal spacing may address a clinically important need for the

Flanagan MM et al.: *To Space or Not to Space: The EPIC Question for Prostate Stereotactic Radiotherapy (SBRT) with or without Hydrogel Rectal Spacer (RS).* Pract Radiat Oncol. (2025)

RS (n=290) vs no RS (n=1815)
Robotic SBRT

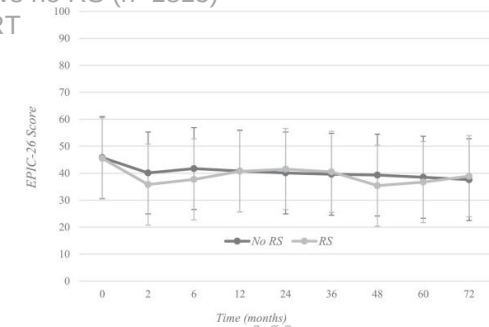


Figure 1.2 *Longitudinal EPIC - 26 Hormonal/Vitality QOL domain mean scores after prostate SBRT by RS over time*

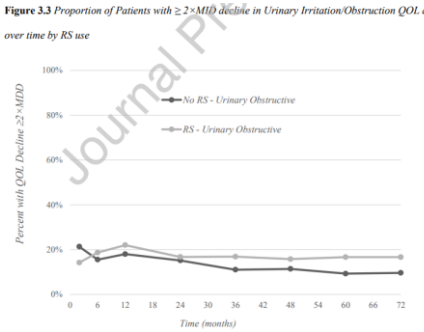


Figure 3.3 *Proportion of Patients with ≥2×MID decline in Urinary Irritation/Obstruction QOL domain over time by RS use*

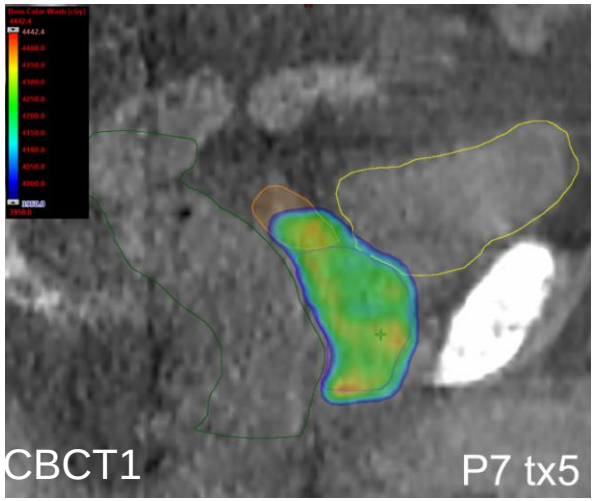
Conclusions

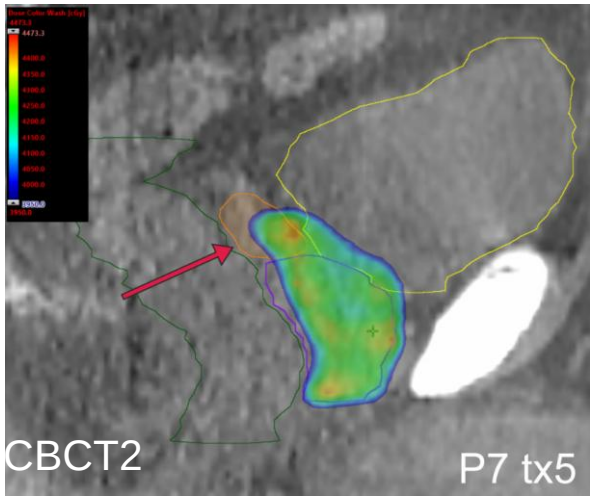
SBRT produced only modest, largely transient QOL declines that resolved by ~6 months. RS did not confer a durable clinically meaningful QOL improvement; an isolated 2×MID signal at 2 months favored RS in select domains, but this was transient, and non-durable.

Vorteil durch Spacer kompensiert durch kleinere Margins & MR oART?

5.2 CBCT oART: Organbewegungen

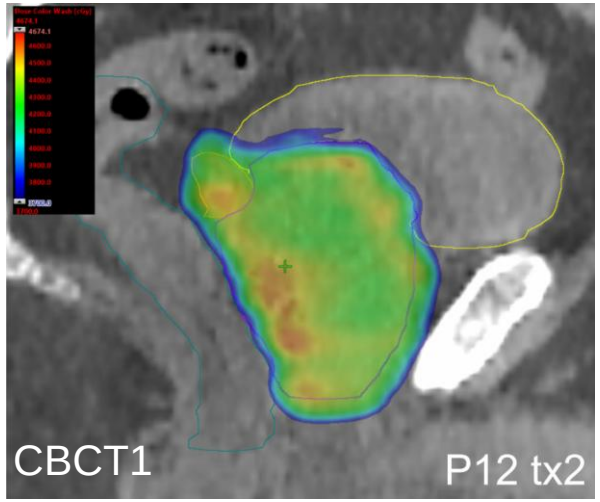
SB / P Bewegung

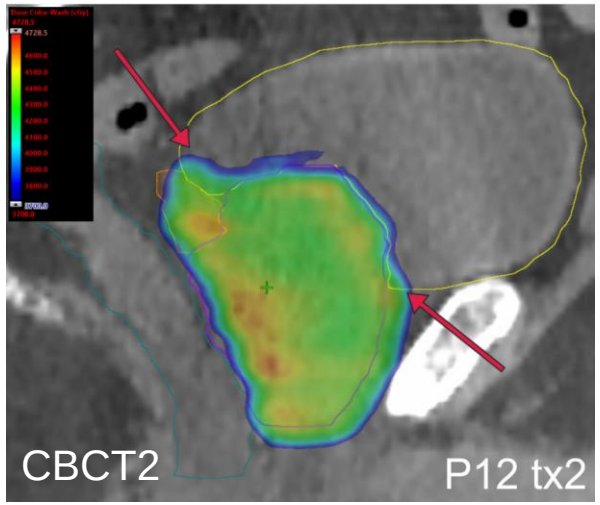




IGRT / oART

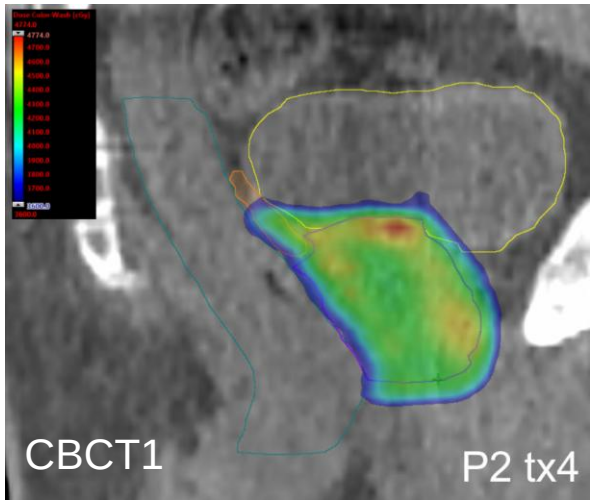
Blasenfüllung

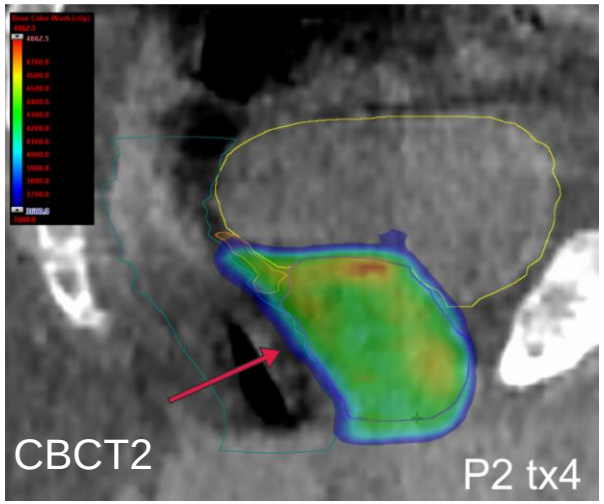




oART

Luft im Rektum





(IGRT) oART

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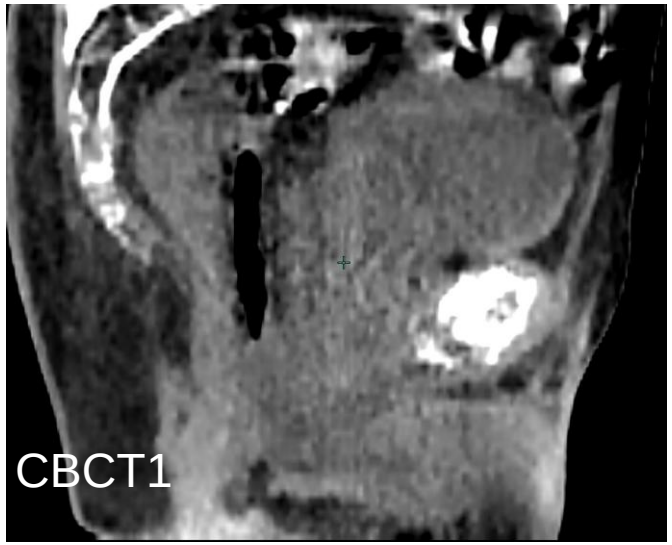
Medizinische Fakultät Mannheim der Universität Heidelberg
Universitätsklinikum Mannheim

Eckl et al. : *Analysis of Online Adaptive Treatment Quality in a Cone-Beam-CT Based Workflow for Ultra-Hypofractionated Radiation Therapy of Prostate Cancer*, Physics and Imaging in Radiation Oncology (2025)

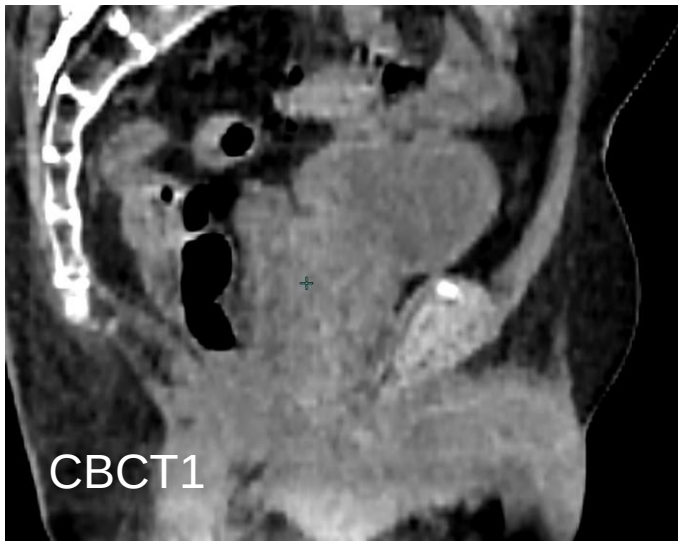
5.2 CBCT oART: Abbruch der Fraktion

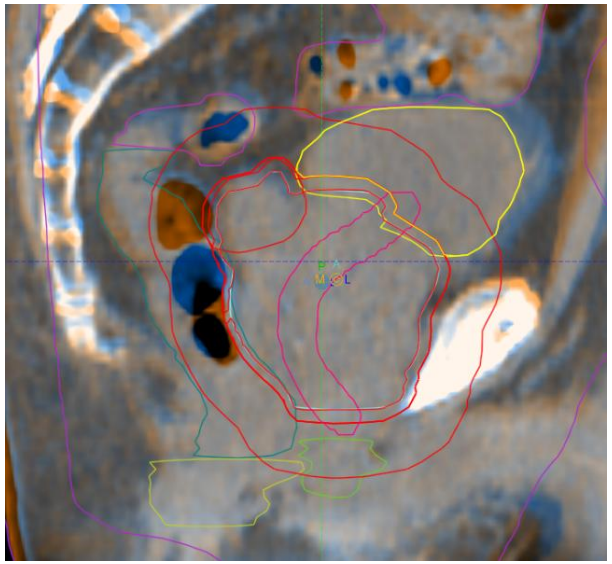
P1



ADP fehlgeschlagen:
V36Gy(rectum) mit 4.4cc
(statt 2cc)

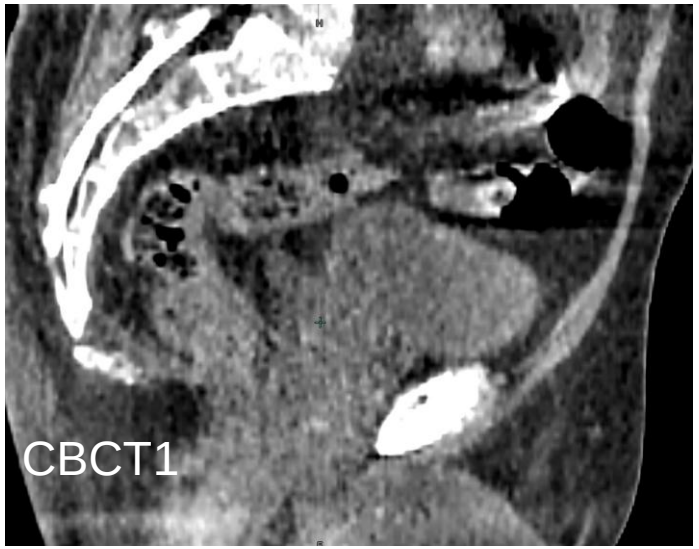
P2

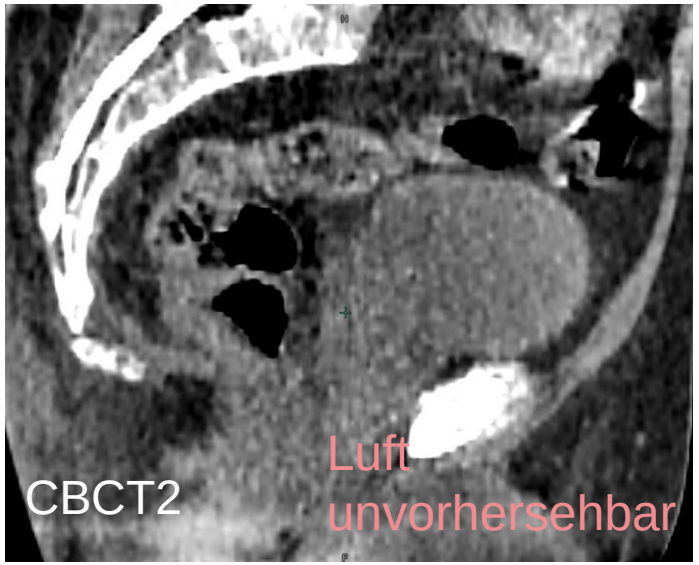




ADP war gut,
CBCT2 erlaubte
keinen Match mit
CBCT1

P3

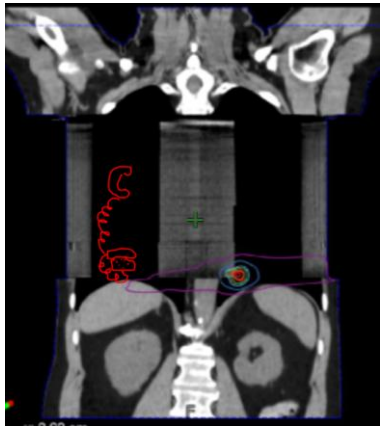


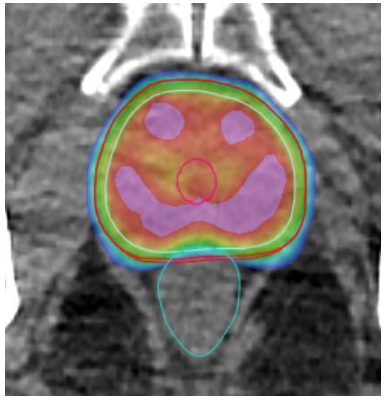


Zusammenfassung: oART vs. IGRT

- **Personalressourcen**, Patientenkollektive, Standardisierung
- sCT vs. **natives CBCT** vs. MRT
- **Lernkurven** (Personal / Patient) & Hinterfragung von IGRT Erfahrungen
- Dosis: Marginkonzepte, Template Constraints, **pro Fraktion vs. Akkumulation**, QA (?)
- Robustheit der täglichen Dosisqualität: **Zeit** & unvorhersehbare Effekte
- Intra- vs. interfraktionelles **Monitoring** & Patienten-Vorbereitung
- Invasivität, Erfahrung, Wirtschaftlichkeit, **Pragmatismus**
- Zukünftige Entwicklungen: Verbesserte Patientenstatistik, Einfluss von KI, Effizienz (**schnelle CBCT** oART, Dosisrate, 3-Fx RT etc.), **Patient Reported Outcomes** (PRO)

Danksagung





5.2 Organbewegungen: Blase und Prostata

Huang S. et al.: *Impact of bladder volume and bladder shape on radiotherapy consistency and treatment interruption in prostate cancer patients*. J Appl Clin Med Phys 2025

275 Patienten, mHF RT

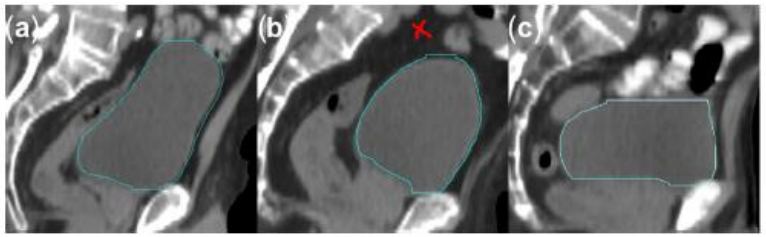


FIGURE 2 Diagram of three bladder shapes on CT sagittal plane. (a) The elongated bladder ($N = 120$): BH/BW ≥ 1.036. (b) The spherical bladder ($N = 86$): 0.836 < BH/BW < 1.036. (c) The oval bladder ($N = 69$): BH/BW ≤ 0.836. BH, bladder height; BW, bladder width.

TABLE 2 The percentage of distribution of shape interruption in three bladder shapes during treatment.

Bladder shape	Amount of repeated scanning	Interruption fraction	Amount of patients interrupted	Patients amount	Total fractions
Elongated bladder	28(4.14%)	15(2.22%)	6	28	677
Spherical bladder	37(7.92%)	28(6.00%)	7	19	467
Oval bladder	20(4.28%)	15(3.21%)	5	19	467

D. M. de Muinck Keizer et al.: *Prostate intrafraction motion during the preparation and delivery of MR-guided radiotherapy sessions on a 1.5T MR-Linac*. Radiother Oncol 2020

Purpose: To evaluate prostate intrafraction motion using MRI during the full course of online adaptive MR-Linac radiotherapy (RT) fractions, in preparation of MR-guided extremely hypofractionated RT.
Material and methods: Five low and intermediate risk prostate cancer patients were treated with 20 × 3.1 Gy fractions on a 1.5T MR-Linac. Each fraction, initial MRI (Pre) scans were obtained at the start of every treatment session. Pre-treatment planning MRI contours were propagated and adapted to this Pre scan after which plan re-optimization was started in the treatment planning system followed by dose delivery. 3D Cine-MR imaging was started simultaneously with beam-on and acquired over the full beam-on period. Prostate intrafraction motion in this cine-MR was determined with a previously validated soft-tissue contrast based tracking algorithm. In addition, absolute accuracy of the method was determined using a 4D phantom.
Results: Prostate motion was completely automatically determined over the full on-couch period (approx. 45 min) with no identified mis-registrations. The translation 95% confidence intervals are within clinically applied margins of 5 mm, and plan adaption for intrafraction motion was required in only 4 out of 100 fractions.
Conclusion: This is the first study to investigate prostate intrafraction motions during entire MR-guided RT sessions on an MR-Linac. We have shown that high quality 3D cine-MR imaging and prostate tracking during RT is feasible with beam-on. The clinically applied margins of 5 mm have proven to be sufficient for these treatments and may potentially be further reduced using intrafraction plan adaptation guided by cine-MR imaging.

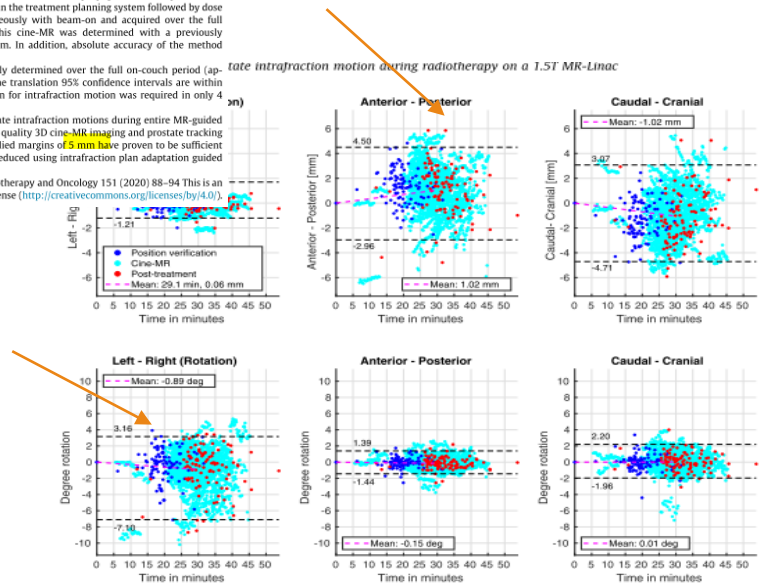


Fig. 5. Overview of the measured intrafraction motion of the position verification scans (PV, blue dots), cine-MR (acquired during beam-on, cyan dots) and post-treatment (Post, red dots) with respect to the pre-treatment scan (Pre). The population average of all measurements is also provided in the graphs. 95% Confidence intervals with their values are provided as the black horizontal dashed lines. Treatments in which an adapted workflow was used and a new treatment plan was created on the position verification scan have been corrected for. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

D. J. Byun et al.: *Strict bladder filling and rectal emptying during prostate SBRT: Does it make a dosimetric or clinical difference?* Radiat Oncol 2020

Abstract

Background: To evaluate inter-fractional variations in bladder and rectum during prostate stereotactic body radiation therapy (SBRT) and determine dosimetric and clinical consequences.

Methods: Eighty-five patients with 510 computed tomography (CT) images were analyzed. Median prescription dose was 40 Gy in 5 fractions. Patients were instructed to maintain a full bladder and empty rectum prior to simulation and each treatment. A single reviewer delineated organs at risk (OARs) on the simulation (Sim-CT) and Cone Beam CTs (CBCT) for analyses.

Results: Bladder and rectum volume reductions were observed throughout the course of SBRT, with largest mean reductions of 86.9 mL (19.0%) for bladder and 6.4 mL (8.7%) for rectum noted at fraction #5 compared to Sim-CT ($P < 0.01$). Higher initial Sim-CT bladder volumes were predictive for greater reduction in absolute bladder volume during treatment ($\rho = -0.69$; $P < 0.01$). Over the course of SBRT, there was a small but significant increase in bladder mean dose ($+4.5 \pm 12.8\%$; $P < 0.01$) but no significant change in the D2cc ($+0.8 \pm 4.0\%$; $P = 0.28$). The mean bladder trigone displacement was in the anterior direction ($+4.02 \pm 6.59$ mm) with a corresponding decrease in mean trigone dose ($-3.6 \pm 9.6\%$; $P < 0.01$) and D2cc ($-6.2 \pm 15.6\%$; $P < 0.01$). There was a small but significant increase in mean rectal dose ($+7.0 \pm 12.9\%$, $P < 0.01$) but a decrease in rectal D2cc ($-2.2 \pm 10.1\%$; $P = 0.04$). No significant correlations were found between relative bladder volume changes, bladder trigone displacements, or rectum volume changes with rates of genitourinary or rectal toxicities.

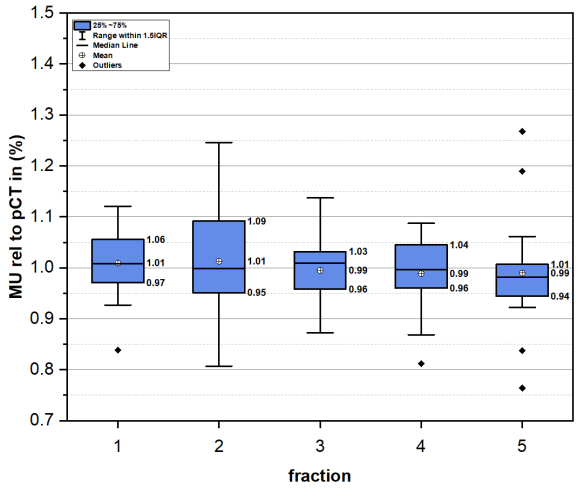
Conclusions: Despite smaller than expected bladder and rectal volumes at the time of treatment compared to the planning scans, dosimetric impact was minimal and not predictive of detrimental clinical outcomes. These results cast doubt on the need for excessively strict bladder filling and rectal emptying protocols in the context of image guided prostate SBRT and prospective studies are needed to determine its necessity.

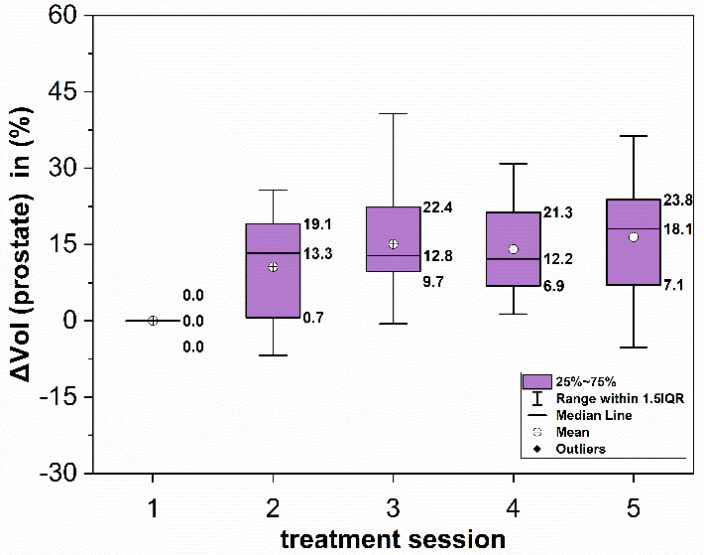
Keywords: SBRT, Prostate cancer, Bladder volume, Rectum volume, Interfractional organ displacement

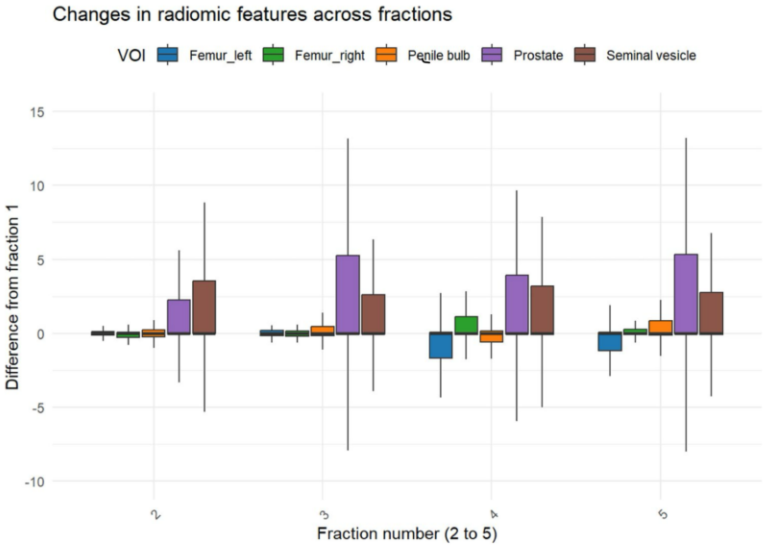
Volumenzunahme & Korrelationen

Table S1: Spearman's correlation coefficients (r) and statistical significance (p). Bold numbers indicate a statistically significant correlation.

Variable 1	Variable 2	r	p
Tx	ΔT	0.50	0.39
Tx	Vol(prostate)	**0.98**	**0.01**
Tx	Vol(bladder)	-0.30	0.62
Tx	Vol(rectum)	0.30	0.62
$Vol(CTV_{CBCT1})$	$DSC(CTV_{CBCT1},CTV_{CBCT2})$	**0.30**	**0.01**
$Vol(CTV_{CBCT1})$	$\Delta V40Gy(CTV)_{CBCT1,CBCT2}$	0.00	0.98
ΔT	Vol(bladder)	**0.34**	**0.00**
ΔT	ΔV37Gy(bladder)	0.07	0.56
ΔT	ΔV36Gy(rectum)	0.03	0.79







Eckl et al. : *Analysis of Online Adaptive Treatment Quality in a Cone-Beam-CT Based Workflow for Ultra-Hypofractionated Radiation Therapy of Prostate Cancer*, Physics and Imaging in Radiation Oncology (2025)

Cvachovec P, Dreher C. Longitudinal stability of HyperSight™-CBCT based radiomic features in patients with CT guided adaptive SBRT for prostate cancer. Sci Rep. 2025

Honorable mentions

Intra-adaptational changes in online adaptive radiotherapy: from the ideal to the real dose

Hanna Malygina[1] · Hendrik Auerbach[1] · Marc Ries[1] · Frank Nuesken[1,2] · Bryan Salazar Zuniga[1] · Sobhan Moumeniahangar[1,3] · Florian Oeschger[1] · Markus Hecht[1] · Jan Palm[1] · Yvonne Dzierma[1,2]

To ensure better bladder sparing, patients are instructed to follow our in-house bladder and bowel preparation instructions, which include the following steps: (1) naturally void the bladder and the bowel; (2) drink 350 ml of liquid within 10 min; (3) engage in light physical activity for 1 h (e.g., walking); (4) attend the appointment (either a planning CT or a CBCT).

Review › Cancers (Basel). 2023 Mar 30;15(7):2081. doi: 10.3390/cancers15072081.

Stereotactic Magnetic Resonance–Guided Adaptive and Non–Adaptive Radiotherapy on Combination MR–Linear Accelerators: Current Practice and Future Directions

John Michael Bryant [1], Joseph Weygand [1], Emily Keit [1], Ruben Cruz-Chamorro [1], Maria L Sandoval [1], Ibrahim M Oraiqat [1], Jacqueline Andreozzi [1], Gage Redler [1], Kujtim Latifi [1], Vladimir Feygelman

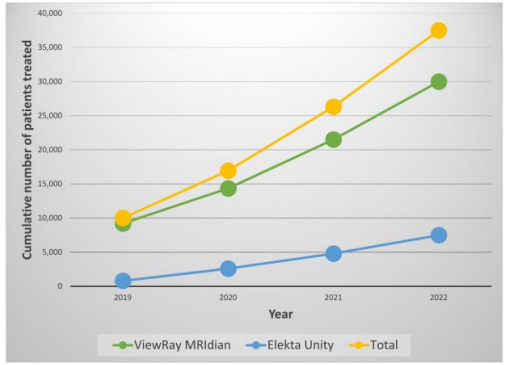


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Figure 3. Cumulative treatments of ViewRay MRIdian and Elekta Unity MRLs per year since 2019. Data used for the creation of Figure 3 were directly provided by ViewRay and from data presented at the 9th annual MR in RT symposium [28].

Fink CA, *Dosimetric benefit of online treatment plan adaptation in stereotactic ultrahypofractionated MR-guided radiotherapy for localized prostate cancer*. Front Oncol. 2024 Feb 15

Although in CT-guided radiotherapy hyaluronic acid spacer gels have been shown to improve rectal dosimetry and hence gastrointestinal toxicity (28), this effect has not been demonstrated, to our knowledge, in MR-guided radiotherapy. Due to the occurrence of rectal fistulas after rectal spacer placement in previous trials (29), their utilization at our center has been omitted in favor of a non-interventional workflow. Nevertheless, dosimetric benefits of MR-guided online-adaptation to the rectum may be reduced by rectal spacers.

Real-time tracking of the prostate via surrogate fiducial markers may permit a similar reduction in PTV margins (30). However, fiducial marker implantation is an invasive procedure accompanied by a slightly increased risk for infection or even fiducial migration in rare cases which might lead to impaired tracking (31). Furthermore, the application of radiopaque fiducials enables rigid-registration and therefore does provide limited information on organ deformation, seminal vesicle location, or bladder and rectal distension. A deviation in the shape of the prostate may not be effectively corrected by standard IGRT applications with or without the use of fiducials. This again underlines the need for deformable image registration and adaptive planning in prostate SBRT at least for some

Results: Twenty-nine prospective studies were identified that met the inclusion criteria and included a total of 2547 patients. The pooled estimates for acute grade 2 or higher (G2+) genitourinary (GU) and gastrointestinal (GI) toxicity for MRg-A-SBRT were 16% (95% confidence interval [CI], 10%–24%) and 4% (95% CI, 2%–7%) and for CT-SBRT they were 28% (95% CI, 23%-33%) and 9% (95% CI, 6%-12%), respectively. On meta-regression, the odds ratios for acute G2+ GU and GI toxicities comparing MRg-A-SBRT and CT-SBRT were 0.56 (95% CI, 0.33–0.97, $p = .04$) and 0.40 (95% CI, 0.17–0.96, $p = .04$), respectively.

Conclusion: MRg-A-SBRT is associated with a significantly reduced risk of acute G2+ GU or GI toxicity compared to CT-SBRT. Longer follow-up will be needed to evaluate late toxicity and disease control outcomes.

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Radiation Oncology

RESEARCH Open Access

Analysis of intra-fractional surface motion during adaptive radiation therapy and relation of internal vs. external position for prostate cancer

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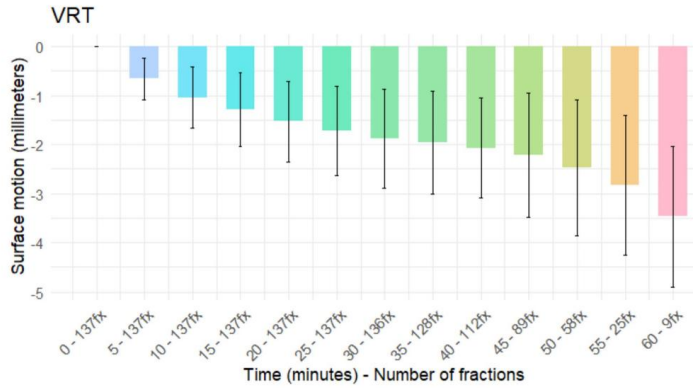


Fig. 2 Vertical (VRT) mean and SD during ART combined with SBRT for prostate cancer

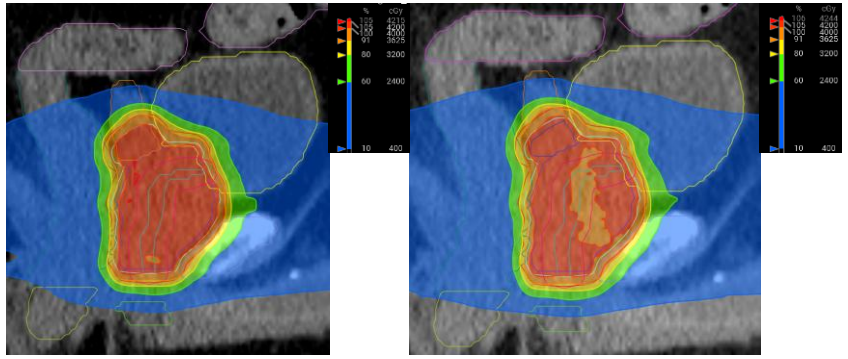
Conclusion

Our study examined the intra-fractional patient motion for 137 ART treatment sessions with SBRT for 30 prostate cancer patients. The findings highlight a notable constant vertical surface shift over the whole course of treatment and not only for the first minutes of the treatment. Further, the relation between the surface and internal target position after the applied translational vCBCT shifts based on this study revealed that SGRT exclusively is not an adequate inter-fractional positioning tool for prostate cancer patients due to the large range of deviations. However additional SGRT-based intra-fractional monitoring can add a value for long duration radiotherapy.

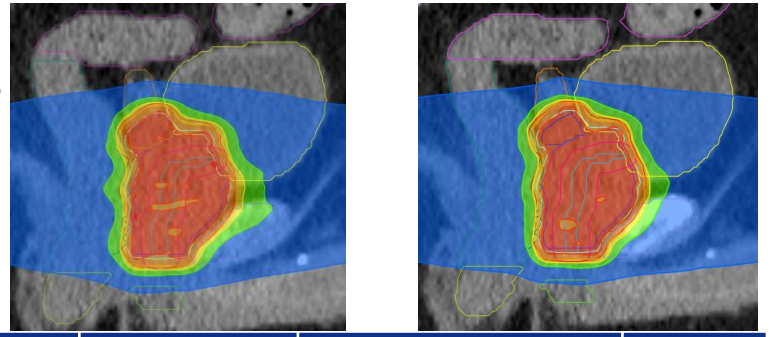
5.3 Urethra & Grenzen der momentanen oART

standard HF

IMRT

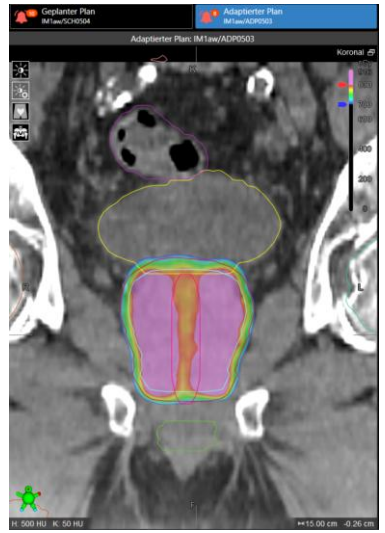


VMAT



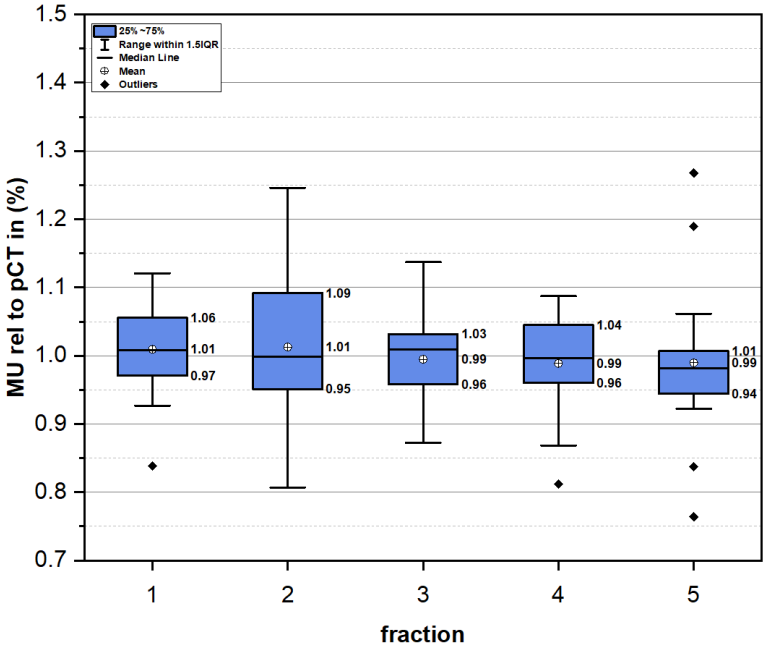
modality	mode	calculation time (s)	MU
IMRT	standard	114+14	3372
	high fidelity	216+63	3142
VMAT	standard	504+18	3192
	high fidelity	1033+61	2486

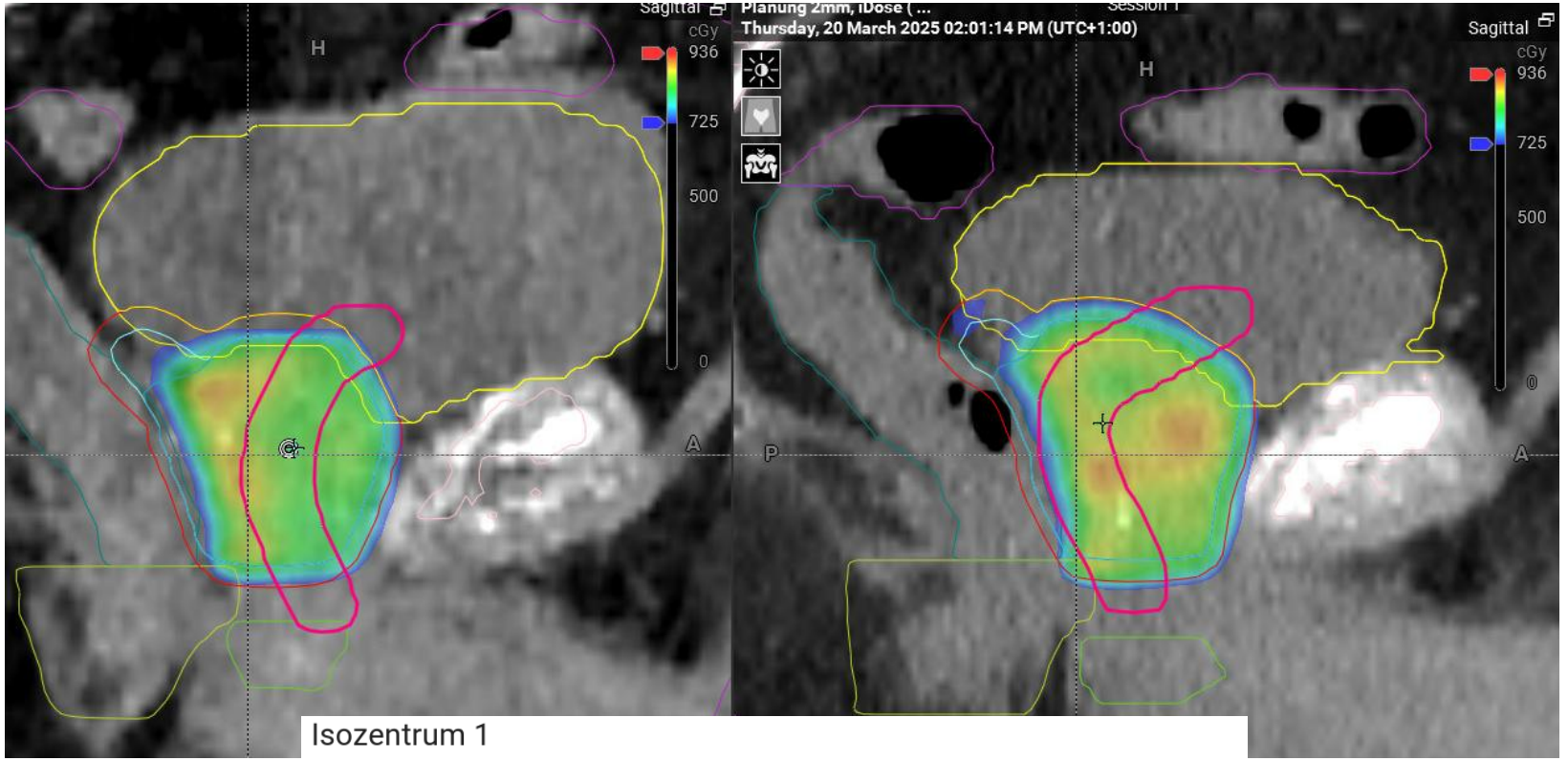
- VMAT Berechnung zu langsam
- Segmentation zu aufwendig
- Template zu komplex
- Dosisrate zu niedrig



Varianz bei Konturierung & ART-Plänen

n=16 pro Gruppe





Isozentrum 1

Position (DICOM): X: 0.00 cm Y: 0.00 cm Z: 0.00 cm
Skala: IEC61217

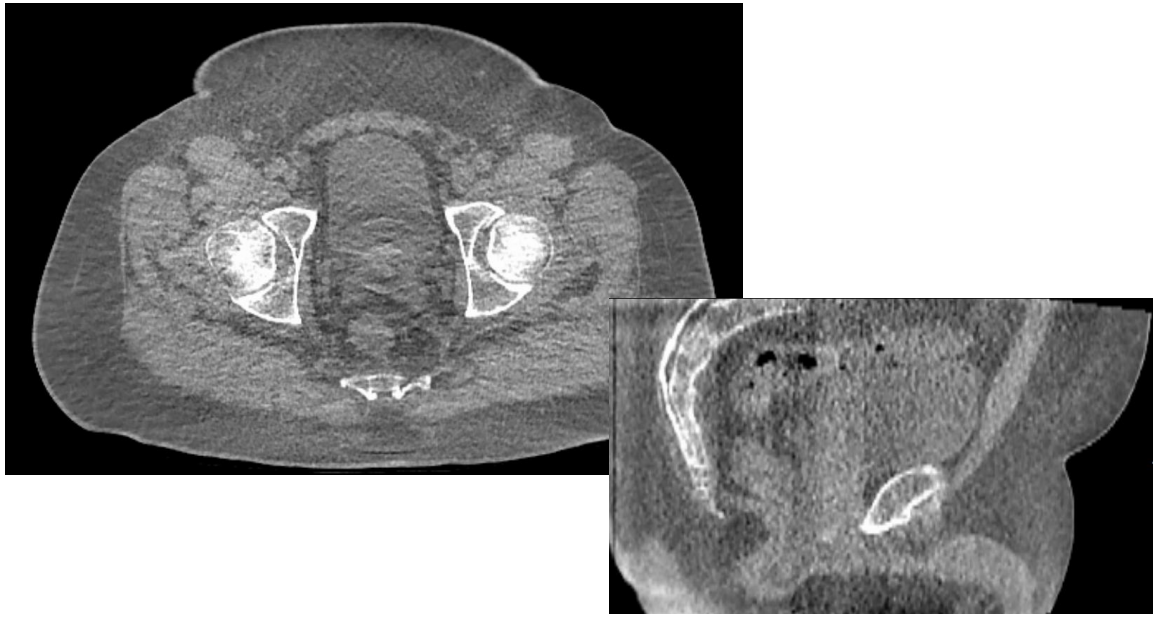
Feldname		Gantry [°]		Kollimator [°]		ME	
		Referenz	Adaptiert	Referenz	Adaptiert	Referenz	Adaptiert
Feld 1	IMRT	180.0°	180.0°	10.0°	10.0°	330.2 ME	337.2 ME
Feld 2	IMRT	150.0°	150.0°	10.0°	10.0°	271.3 ME	259.1 ME
Feld 3	IMRT	120.0°	120.0°	10.0°	10.0°	294.5 ME	203.4 ME
Feld 4	IMRT	90.0°	90.0°	10.0°	10.0°	466.2 ME	468.0 ME
Feld 5	IMRT	60.0°	60.0°	10.0°	10.0°	379.4 ME	325.2 ME
Feld 6	IMRT	30.0°	30.0°	10.0°	10.0°	407.9 ME	343.0 ME
Feld 7	IMRT	0.0°	0.0°	10.0°	10.0°	330.8 ME	273.2 ME
Feld 8	IMRT	330.0°	330.0°	10.0°	10.0°	320.9 ME	304.3 ME
Feld 9	IMRT	300.0°	300.0°	10.0°	10.0°	385.4 ME	324.9 ME
Feld 10	IMRT	270.0°	270.0°	10.0°	10.0°	319.7 ME	339.3 ME
Feld 11	IMRT	240.0°	240.0°	10.0°	10.0°	268.4 ME	228.3 ME
Feld 12	IMRT	210.0°	210.0°	10.0°	10.0°	282.6 ME	238.2 ME

Gesamt

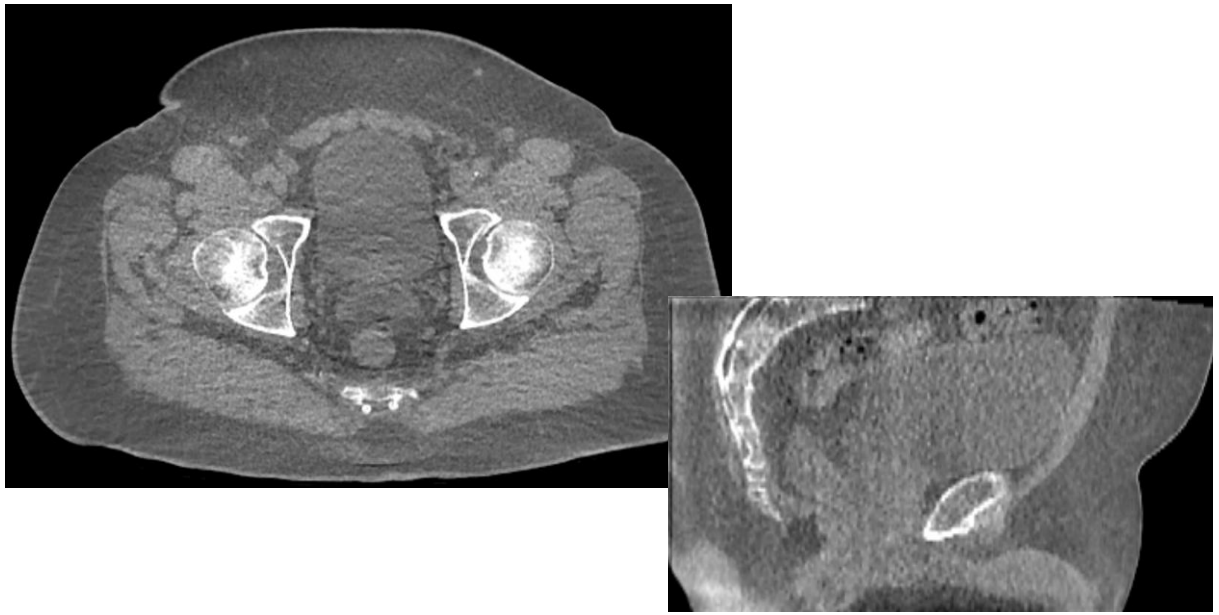
Gesamt	4057.3 ME	3644.1 ME

HyperSight calibration: Pelvis Large preset

Pelvis



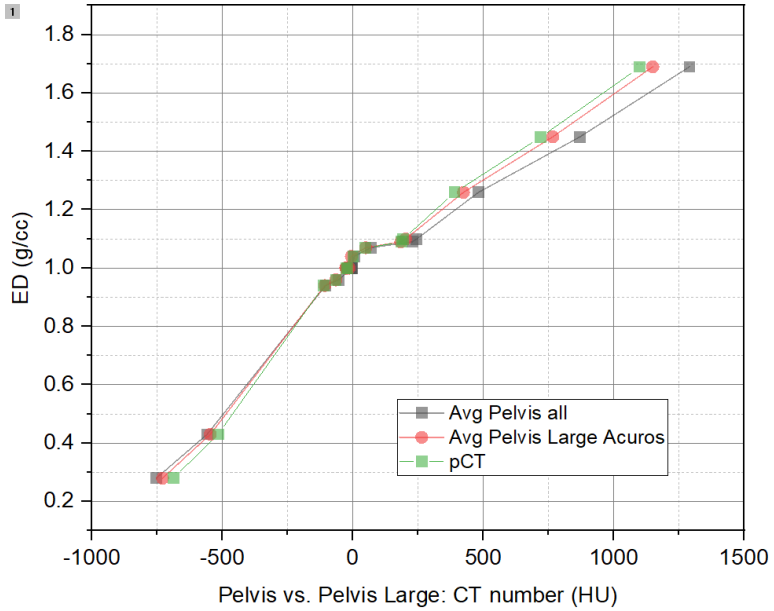
Pelvis Large



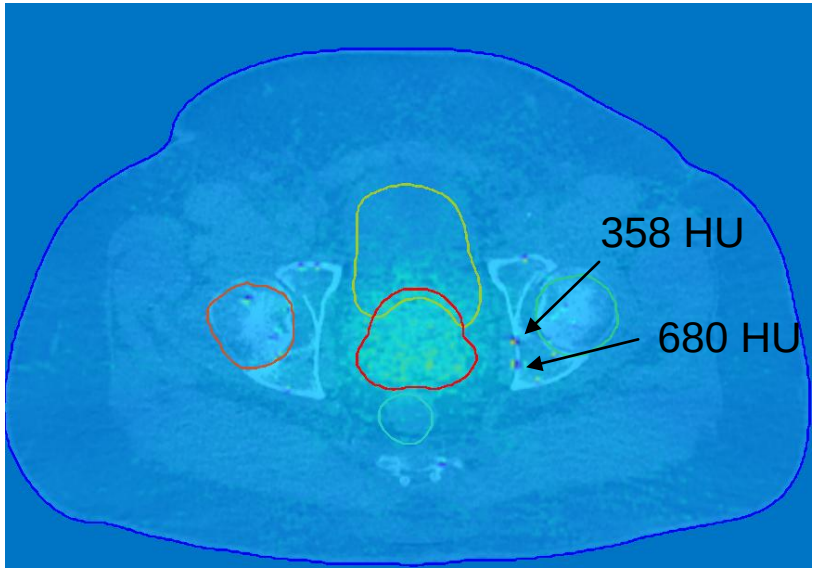
kV-CBCT mode	Energy [kV]	Total mAs	Proj count	mA / ms per proj	Scan time [sec]	CTDIvol			Local dose values $CTDI_{100,\,pos}$ for center, top, bottom, left, right positions, 16 cm / 32 cm [mGy]
						16 cm Head phantom [mGy]	32 cm Body phantom [mGy]	Conversion factor 16 cm to 32 cm	
Pelvis		469	409	80 / 14.3	5.9	20.2	8.91		20.9, 17.2, 23.9, 29.1, 9.32 / 6.34, 7.47, 14.5, 17.3, 1.40
Pelvis Large	140	528		90 / 14.3		30.1	13.6	2.23	31.1, 25.7, 35.5, 43.3, 14.2 / 9.78, 11.4, 21.9, 26.1, 2.28

Pelvis vs. Pelvis Large calibration: Patient plan

HU-ED calibration curves

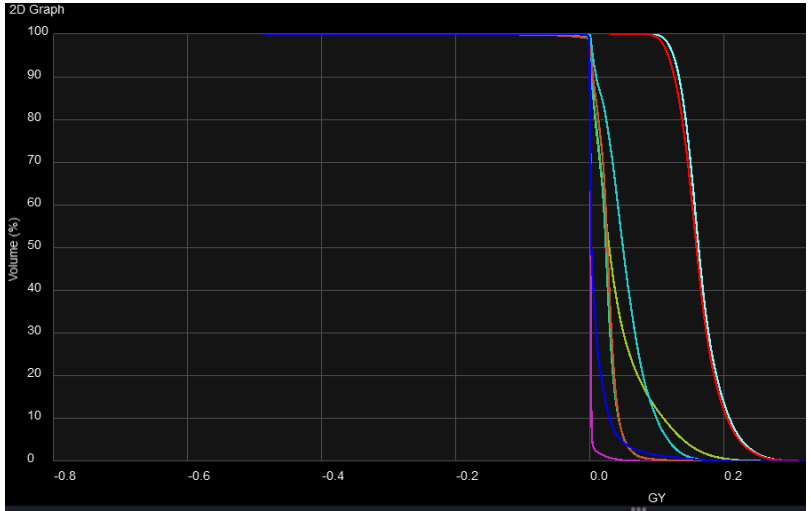


CBCT_b



PTV dose difference : +0.2-0.3Gy

DVH of difference plan

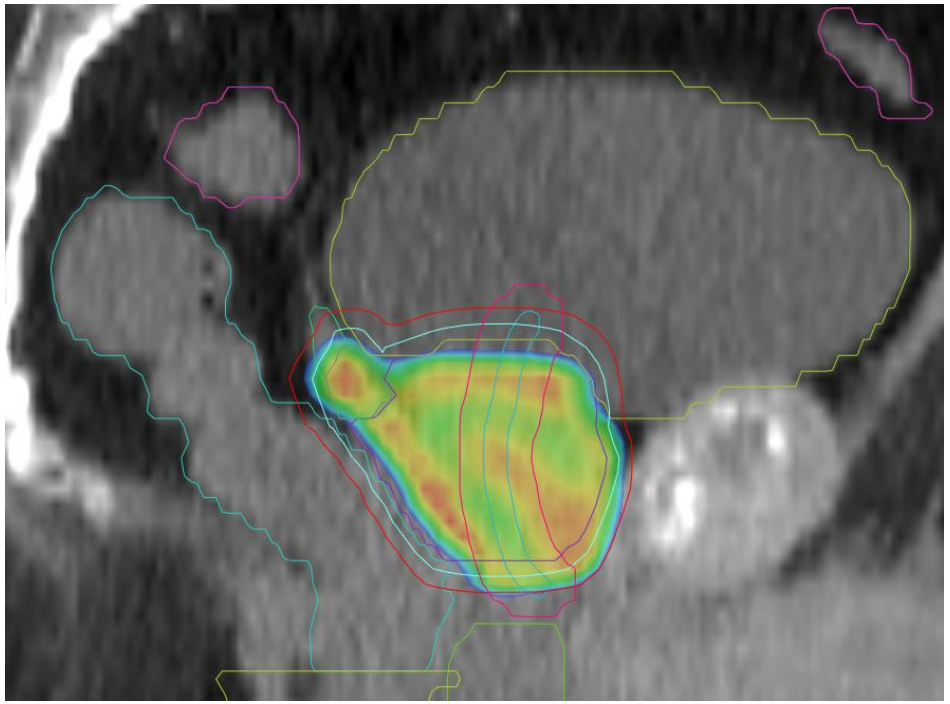


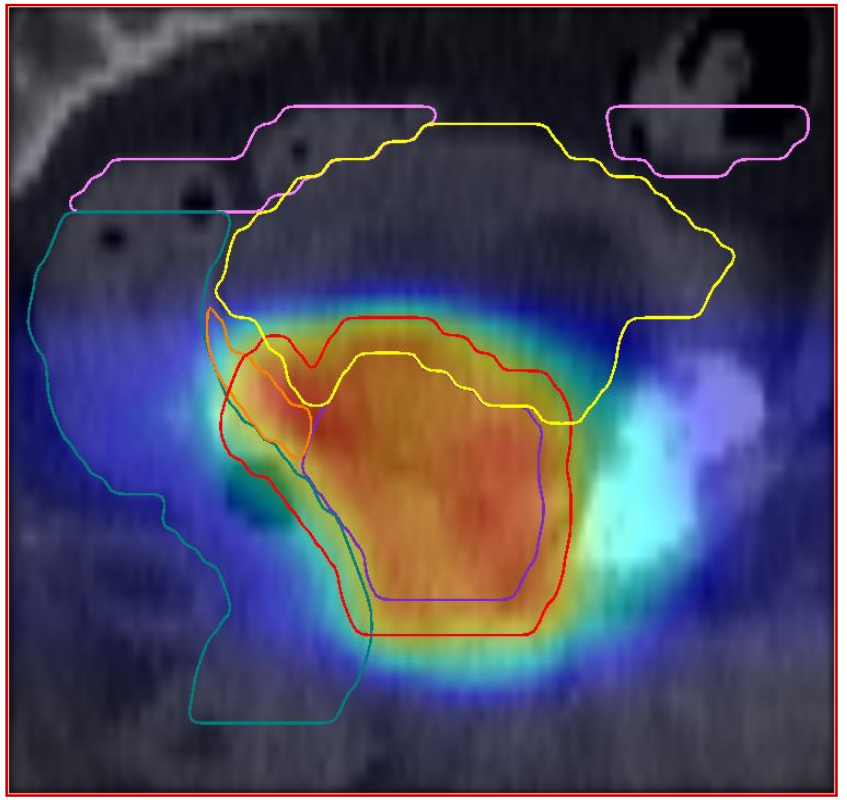
Histogram Statistics: No Protocol Selected

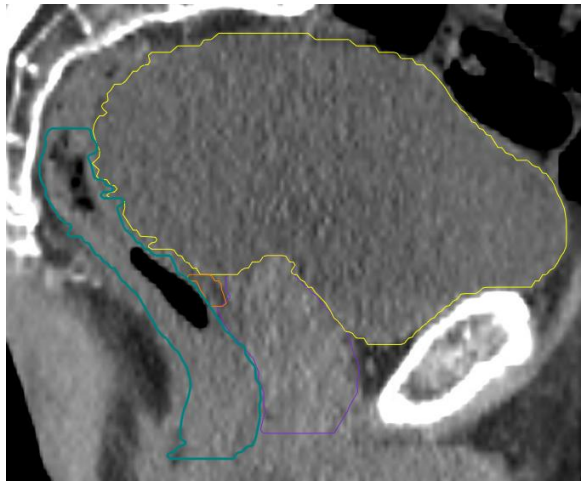
Structure	Data Source	Type	Volume Name	Structure Volume (cm³)	Min Value	Mean Value	Max Value	Cons
Bladder	Velocity	ORGAN	Pnorm-Plarge CBCTb	319.9	-0.00	0.04	0.35	
Bowel	Velocity	ORGAN	Pnorm-Plarge CBCTb	204.6	-0.00	0.00	0.11	
CTV	Velocity	CTV	Pnorm-Plarge CBCTb	136.4	0.08	0.17	0.37	
Femur head & neck left	Velocity	ORGAN	Pnorm-Plarge CBCTb	232.4	-0.21	0.02	0.33	
Femur head & neck right	Velocity	ORGAN	Pnorm-Plarge CBCTb	239.9	-0.30	0.03	0.35	
PTV	Velocity	PTV	Pnorm-Plarge CBCTb	186.5	0.03	0.16	0.89	
Rectum	Velocity	ORGAN	Pnorm-Plarge CBCTb	97.0	-0.00	0.05	0.26	
BODY	Velocity	EXTERNAL	Pnorm-Plarge CBCTb	23750.9	-0.49	0.01	0.89	

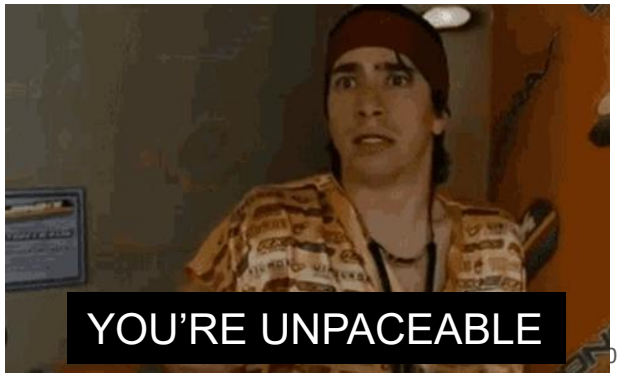
Ungeeignete Anatomien für PACE

Phase 1	Approved IM144 ✔ IMRT-Plan mit 12 abstandsgleichen Feldern LB3E
Targets Summary	4 / 7
P1 CTV **D0.04 cm3≤4200 cGy**	4499 cGy
P CTV **V4000 cGy≥98.0 %** V4000 cGy≥95.0 %	90.0 %
P1 CTV **V4200 cGy≥20.0 %**	83.4 %
P2 CTV **Dmax<5438 cGy**	4502 cGy
P1 PTV **D98.0 %≥3440 cGy**	3553 cGy
P1 PTV **Dmax≤4800 cGy**	4502 cGy
P1 PTV **V3625 cGy≥98.0 %** V3625 cGy≥95.0 %	96.6 %
P1 PTV-CTV **Dmax≤125.0 %**	124.2 %
P1 PTV2cm **D0.04 cm3≤4800 cGy**	4499 cGy
P1 PTV2cm **V3000 cGy≥85.0 %**	93.5 %
P1 PTV2cm-PTV **Dmax≤125.0 %**	140.1 %
PR PTV2cm-PTV **V3000 cGy≥80.0 %** V3000 cGy≥70.0 %	63.4 %
Organs Summary	7 / 18
P2 Anus **Dmean≤1200 cGy**	172 cGy
P1 Bladder **V1810 cGy≤40.0 %**	25.2 %
P1 Bladder **V3600 cGy≤10.00 cm3**	16.62 cm3
P1 Bladder **V3700 cGy≤10.00 cm3**	9.69 cm3









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Universitätsklinikum Mannheim

Software Environment

Planning CT	Auto-Segmentation	PTV-Segmentation & Planning	Scheduling	Documentation
Brilliance BigBore, Philips	Syngo Via MM Image Suite	Ethos Treatment Management, Varian	Aria, Varian & Mosaiq, Elekta	Ethos Treatment Management, Varian & Mosaiq, Elekta

Manual Segmentation	Sum Plans & QA	RT & SGRT & online QA
Monaco, Elekta	Velocity, Varian & Veriqa, PTW & dosimetry equipment	Ethos RT System + HyperSight CBCT, Varian
Eclipse, Varian	Eclipse, Varian	AlignRT, Vision RT
		Mobius3D, Varian