Adaptive Radiotherapy in patient Radiation Protection

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Line

- Adaptive RT
- What about its utility?
- Patient’s radioprotection during radiotherapy
- Doses during adaptive radiotherapy using ionizing radiations: are these clinically relevant?
- RM adaptive radiotherapy (not only for radioprotection reasons)
- Problems in ART: dose accumulation and deformable image registration
- Conclusions

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- What about its utility?
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- ~~Problems in ART: dose accumulation and deformable image registration~~
- Conclusions

Adaptive radiotherapy

- Radiotherapy has evolved significantly over the years. Traditionally, treatment plans were based on initial scans used throughout the treatment course, accounting for changes in the patient's anatomy by additional margins to targets.
- However, the field has moved towards decreasing margins with the advancement of delivery and targeting accuracy in order to decrease toxicity, and the **increasing use of image guidance has illuminated patient anatomical changes such as organ deformation, weight loss, tumour shrinkage, and even biological changes** that are unaccounted for by the conventional approach.

Adaptive radiotherapy (ART) addresses this by adjusting treatment plans according to these changes.

ART can be conducted in two ways:

- online (adjustments made during treatment sessions)
- offline (adjustments made between treatment sessions).

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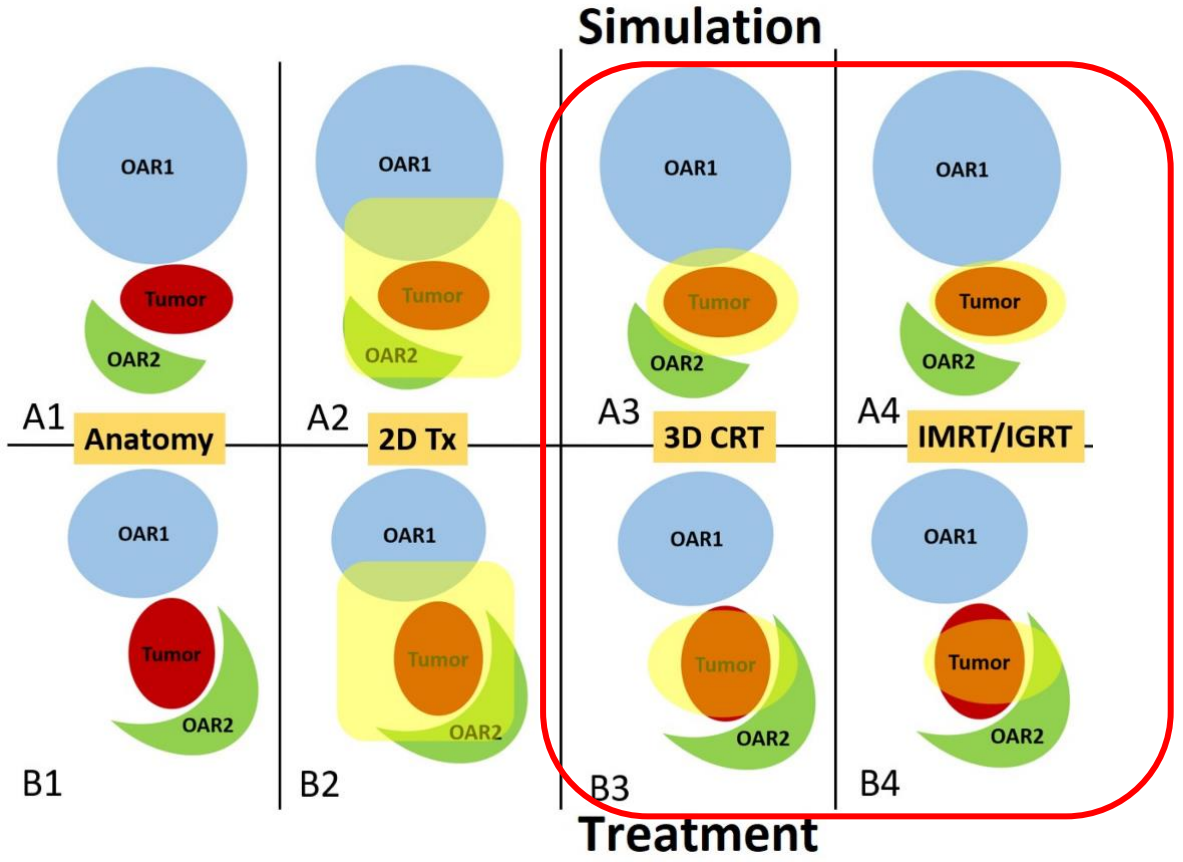
Nevertheless, as demonstrated in panels A3-4 and B3-4, when there is a **disparity between the anatomy on the treatment day and the anatomy during the simulation, as the treatment plan becomes increasingly sophisticated and tightly conformal to the original targets**, **the anatomical changes can lead to a greater deviation from the initial intention**. Consequently, the coverage of the tumour dose is compromised, and the OARs receive a higher dose than planning



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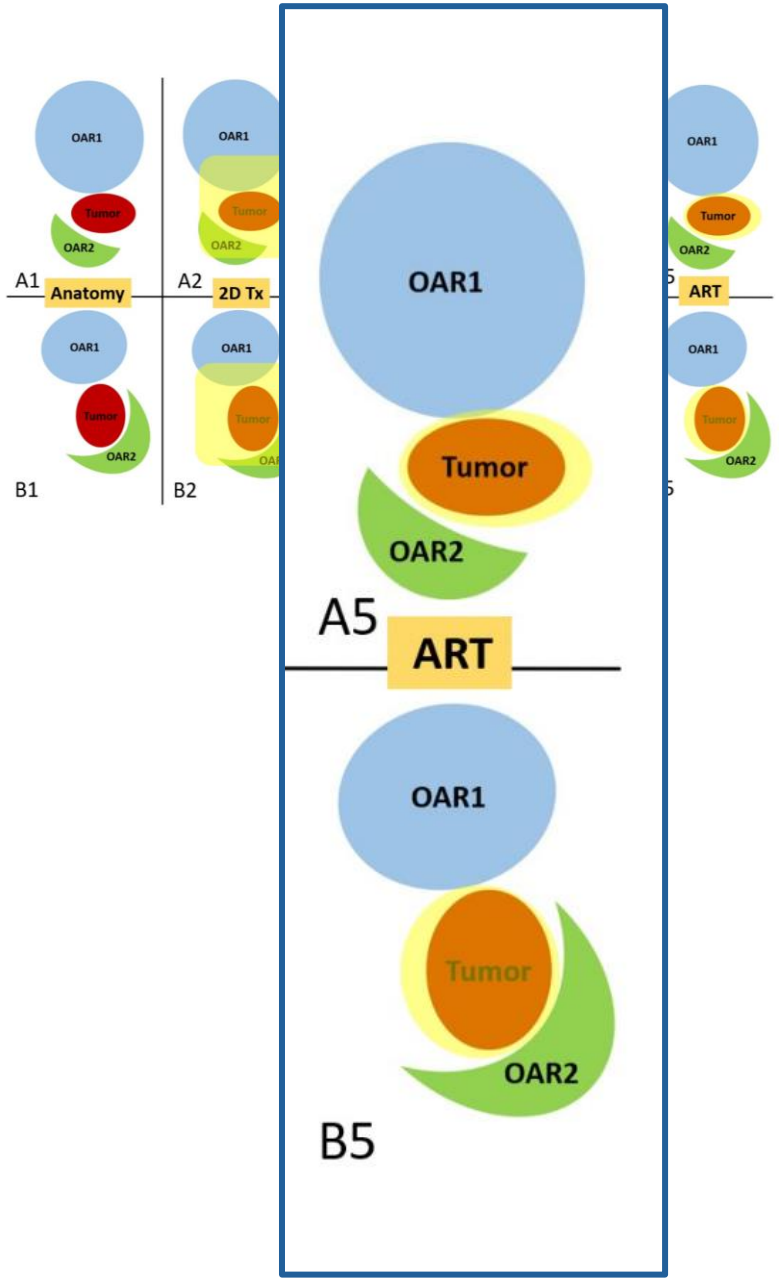

- - ART signifies a fundamental change from conventional radiotherapy, **as it involves dynamically reoptimizing the treatment plan to accommodate changes in the patient's anatomy**.

- - This guarantees the **preservation of accurate radiation dosage to the tumour while specifically protecting nearby OARs**, thus optimizing the therapeutic ratio that can be achieved with advanced radiotherapy technology.

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On-line vs off-line ART

Table 1. Summary of offline vs. online ART.

	Offline ART	Online ART
Frequency	Offline ART involves evaluation/adjustments to the treatment plan in between treatment sessions, with the patient off the table. Plan adjustments are based on anatomy imaged at a certain timepoint and applied for later sessions. It is often applied in lower frequency such as mid-treatment, biweekly, or weekly.	Online ART involves evaluations/adjustments based on the session anatomy, while the patient stays on the treatment table, and is applied for the treatment of the same session. It is currently more often applied in each treatment session.

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Complexity	When performed less frequently, it is generally less resource-intensive compared to online ART. At the same time, it could still be staff-time-demanding if offline ART has a less streamlined or automated workflow than available in online ART.	Online ART can be more complex and resource-intensive compared to offline ART because it requires specialized equipment and software and may be carried out more frequently.

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Treatment planning	Offline ART is not conducted on patient images obtained in the session the adaptive plan is intended to be applied. Instead, planning is conducted offline on previously obtained images to apply in future sessions.	It allows for a highly individualized and precise treatment plan for each session, taking into account the new anatomy in each treatment session. The adaptive plan is made based on the session image and applied to the same session.

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Clinical Applications	It is suitable for patients with tumors, OARs, and body habitus that are less likely to experience rapid anatomical changes and when the tumor is relatively distant from critical structures. It is commonly employed in situations such as head and neck cancers. Patient setup changes could also trigger the need for offline adaptation.	Used for cases where anatomical changes are expected on a daily basis. It is commonly employed in situations such as abdominal and pelvic malignancies. Based on the optimal trade-off between clinical benefits and required resources, the online ART platform may also be used for various disease sites to apply daily, weekly, or on-demand plan adaptation.

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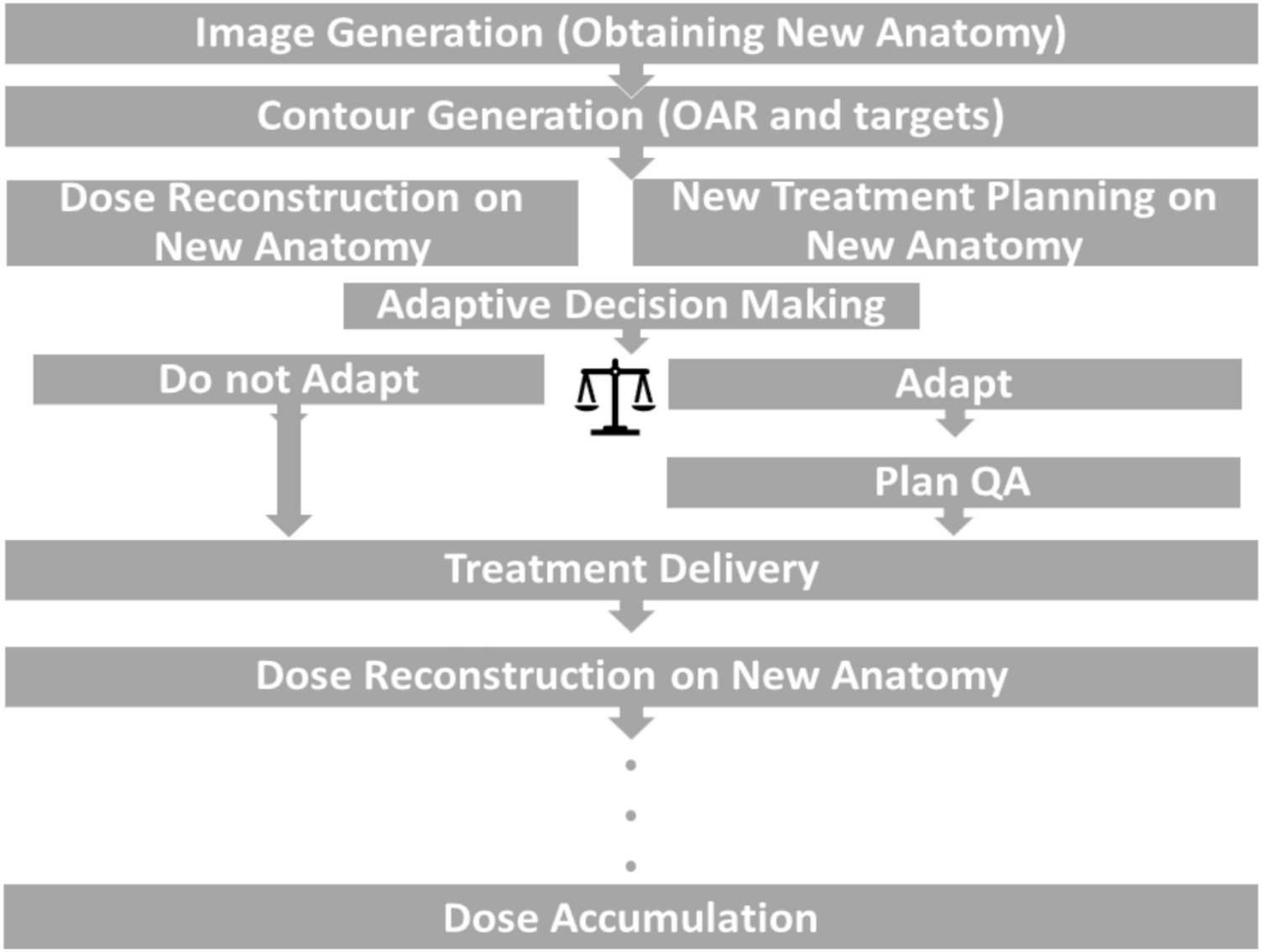
Basic workflow ART



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Basic principles of radioprotection

- Justification of the exposition
- Optimization of the dose
- Limitation of the maximal dose

Basic principles of radioprotection for patients treated with RT

- Justification of the exposition → radical/palliative **treatment of the tumor** → informed consent
- Optimization of the dose → **great attention to OAR, to dose distribution to G and CTV, to reduce unnecessary dose out of the target**
- Limitation of the maximal dose → **the maximal doses for general population are too low for patients treated with RT → but also for these patients the attention has to be posed to reduce the unnecessary dose and to deliver the minimum necessary dose**

Dose during ART workflow

Is it clinically relevant or not?

Radiation exposure during the acquisition of the CBCT scan, while minimal compared with the dose delivered during RT treatment, nevertheless prevents the use of CBCT for repeated images throughout the fraction; therefore, CBCT cannot be used for real-time ART or intrafraction motion assessment (46,56). The imaging dose for kilovoltage-CBCT typically ranges from 0.2 to 2 cGy per image (20,29). Skin dose has been measured to be a fraction of a centigray for low-dose head and neck imaging and 7 cGy for high-dose pelvic imaging (56).

In summary, the key advantages of CBCT-based ART include its ease of integration into the RT workflow and potential for rapid imaging and replanning, leading to feasible time frames for online adaptation. The major drawback is the inferior image quality due to poor resolution, scatter, and artifacts, which leads to reduced soft-tissue contrast and increased dosimetric uncertainty.

As online ART relies heavily on the quality of onboard imaging for treatment adaptation, there has been much enthusiasm about MRI platforms for online ART. Hybrid systems that combine linear accelerators with onboard MRI (MRI-linear accelerator systems) are commercially available and have been used in most clinical implementations of online ART to date (46), including in patients with lung tumors (38), liver and other abdominal malignancies (22), pancreas cancer (28), colorectal cancer (23), prostate cancer (21,37), and adrenal metastases (36).

While implementing MRI-guided ART can require a substantial investment of resources and pose many technical challenges, the increased soft-tissue resolution over CBCT and the potential for real-time and functional imaging offer important advantages to MRI-linear accelerator implementation for ART

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Dose assessment for daily cone-beam CT in lung radiotherapy patients and its combination with treatment planning

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Abstract

With the increased use of X-ray imaging for patient alignment in external beam radiation therapy, particularly with cone-beam computed tomography (CBCT), the additional dose received by patients has become of greater consideration. In this study, we analysed the radiation dose from CBCT for clinical lung radiotherapy and assessed its relative contribution when combined with radiation treatment planning for a variety of lung radiotherapy techniques. The Monte Carlo simulation program ImpactMC was used to calculate the 3D dose delivered by a Varian TrueBeam linear accelerator to patients undergoing thorax CBCT imaging. The concomitant dose was calculated by simulating the daily CBCT irradiation of ten lung cancer patients. Each case was planned with a total dose of 50-60 Gy to the target lesion in 25-30 fractions using the 3DCRT or IMRT plan and retrospectively planned using VMAT. For each clinical case, the calculated CBCT dose was summed with the planned dose, and the dose to lungs, heart, and spinal cord were analysed according to conventional dose conformity metrics. Our results indicate greater variations in dose to the heart, lungs, and spinal cord based on planning technique, (3DCRT, IMRT, VMAT) than from the inclusion of daily cone-beam imaging doses over 25-30 fractions. The average doses from CBCT imaging per fraction to the lungs, heart and spinal cord were 0.52 ± 0.10, 0.49 ± 0.15 and 0.39 ± 0.08 cGy, respectively. Lung dose variations were related to the patient's size and body composition. Over a treatment course, this may result in an additional mean absorbed dose of 0.15-0.2 Gy. For lung V5, the imaging dose resulted in an average increase of ~ 0.6% of the total volume receiving 5 Gy. The increase in V20 was more dependent on the planning technique, with 3DCRT increasing by 0.11 ± 0.09% with imaging and IMRT and VMAT increasing by 0.17 ± 0.05% and 0.2 ± 0.06%, respectively. In this study, we assessed the concomitant dose for daily CBCT lung cancer patients undergoing radiotherapy. The additional radiation dose to the normal lungs from daily CBCT was found to range, from 0.15 to 0.2 Gy when the patient was treated with 25-30 fractions. Consideration of potential variation in relative biological effectiveness between kilovoltage imaging and megavoltage treatment dose was outside the scope of this study. Regardless of this, our results show that the assessment of imaging dose can be incorporated into the treatment planning process and the relative effect on overall dose distribution was small compared to the difference among planning techniques.

Keywords: 3DCRT; CBCT Dose; Daily CBCT; IMRT; Lung cancer; Monte Carlo; VMAT.

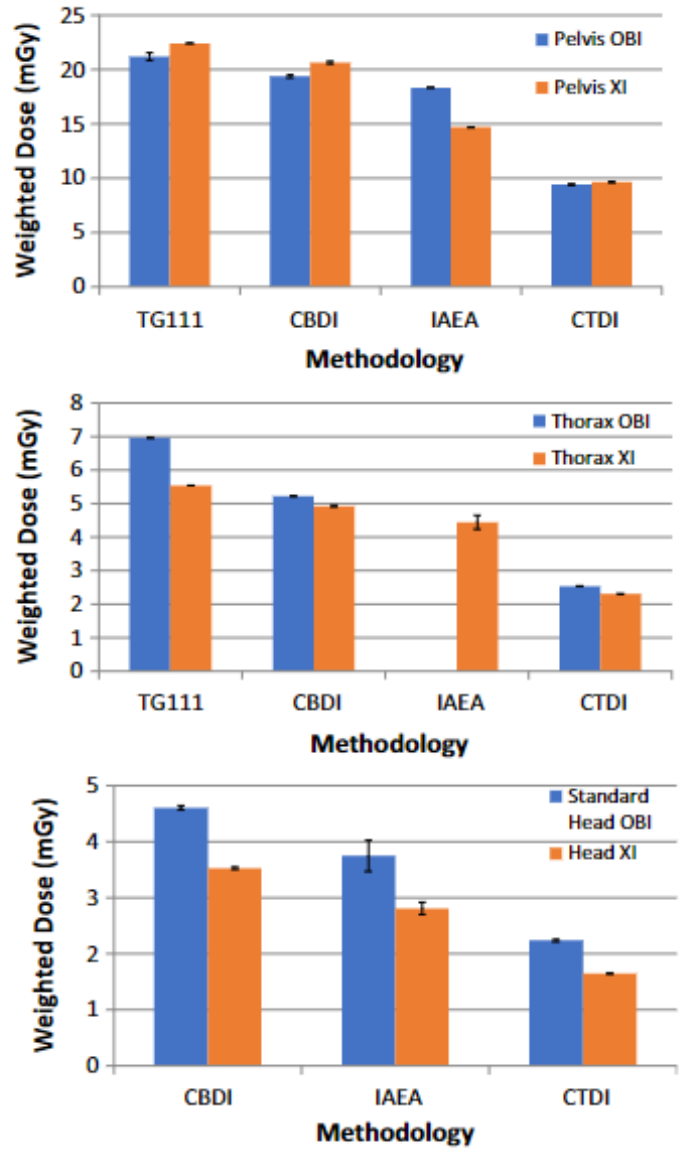

Fig. 4. Comparison of TG111, CBDI, IAEA, and CTDI methodologies on the OBI and XI imaging systems for pelvis (a) and thorax (b) protocols. The IAEA was not evaluated for OBI thorax. Comparison of CBDI, IAEA, and CTDI methodologies for OBI standard head and XI head protocols is shown in (c). Error bars represent one standard deviation from repeated measurements.

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Investigation of the radiation dose from cone-beam CT for image-guided radiotherapy: A comparison of methodologies

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Clinical dosimetric confirmation of adaptive procedures

lung

Abstract

Background Daily adaptive radiation therapy (ART) of patients with non-small cell lung cancer (NSCLC) lowers organs at risk exposure while maintaining the planning target volume (PTV) coverage. Thus, ART allows an isotoxic approach with increased doses to the PTV that could improve local tumor control. Herein we evaluate daily online ART strategies regarding their impact on relevant dose-volume metrics.

Methods Daily cone-beam CTs ($1 \times n = 28$, $1 \times n = 29$, $11 \times n = 30$) of 13 stage III NSCLC patients were converted into synthetic CTs (sCTs). Treatment plans (TPs) were created retrospectively on the first-fraction sCTs (sCT_1) and subsequently transferred unaltered to the sCTs of the remaining fractions of each patient (sCT_{2-n}) (IGRT scenario). Two additional TPs were generated on sCT_{2-n}: one minimizing the lung-dose while preserving the $D_{95\%}$(PTV) (isoeffective scenario), the other escalating the $D_{95\%}$(PTV) with a constant $V_{20Gy}(lung_{ipsilateral})$ (isotoxic scenario).

Results Compared to the original TPs predicted dose, the median $D_{95\%}$(PTV) in the IGRT scenario decreased by 1.6 Gy ± 4.2 Gy while the $V_{20Gy}(lung_{ipsilateral})$ increased in median by 1.1% ± 4.4%. The isoeffective scenario preserved the PTV coverage and reduced the median $V_{20Gy}(lung_{ipsilateral})$ by 3.1% ± 3.6%. Furthermore, the median $V_{5\%}$(heart) decreased by 2.9% ± 6.4%. With an isotoxic prescription, a median dose-escalation to the gross target volume of 10.0 Gy ± 8.1 Gy without increasing the $V_{20Gy}(lung_{ipsilateral})$ and $V_{5\%}$(heart) was feasible.

Conclusions We demonstrated that even without reducing safety margins, ART can reduce lung-doses, while still reaching adequate target coverage or escalate target doses without increasing ipsilateral lung exposure. Clinical benefits by means of toxicity and local control of both strategies should be evaluated in prospective clinical trials.

Keywords Adaptive radiation therapy, stage III NSCLC, Isotoxic dose-escalation, Isoeffective organ at risk sparing

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prostate

Inter-fraction organ variations cause deviations between planned and delivered doses in patients receiving radiotherapy for prostate cancer. This study compared planned (D_P) *vs* accumulated doses (D_A) obtained from daily cone-beam computed tomography (CBCT) scans in high-risk- prostate cancer with pelvic lymph nodes irradiation. An intensity-based deformable image registration algorithm used to estimate contours for D_A was validated using geometrical agreement between radiation oncologist's and deformable image registration algorithm propagated contours. Spearman rank correlations (r_s) between geometric measures and changes in organ volumes were evaluated for 20 cases. Dose-volume (DV) differences between D_A and D_P were compared (Wilcoxon rank test, $p < 0.05$). A novel region-of-interest (ROI) method was developed and mean doses were analyzed. Geometrical measures for the prostate and organ-at-risk contours were within clinically acceptable criteria. Inter-group mean (± SD) CBCT volumes for the rectum were larger compared to planning CT (pCT) (51.1 ± 11.3 cm^3 *vs* 46.6 ± 16.1 cm^3), and were moderately correlated with variations in pCT volumes, rs = 0.663, $p < 0.01$. Mean rectum DV for D_A was higher at V30-40 Gy and lower at V70-75 Gy, $p < 0.05$. Mean bladder CBCT volumes were smaller compared to pCT (198.8 ± 55 cm^3 *vs* 211.5 ± 89.1 cm^3), and was moderately correlated with pCT volumes, rs = 0.789, $p < 0.01$. Bladder D_A was higher at V30-65 Gy and lower at V70-75 Gy ($p < 0.05$). For the ROI method, rectum and bladder D_A were lower at 5 to 10 mm ($p < 0.01$) as compared to D_P, whilst bladder D_A was higher than D_P at 20 to 50 mm ($p < 0.01$). Generated D_A demonstrated significant differences in organ-at-risk doses as compared to D_P. A well-constructed workflow incorporating a ROI DV-extraction method has been validated in terms of efficiency and accuracy designed for seamless integration in the clinic to guide future plan adaptation.

Size-specific Effective Dose (SED)

- Results from the Monte Carlo simulations carried out in this study have compared values for SEDs between phantoms of different stature.
- This shows that patients who **are shorter or lighter will receive (significantly) higher doses if similar exposure factors and field sizes are used for CBCT scans on all patients**.

"A person who is 5 cm shorter will receive a SED that is 3%–7% greater for a chest scan and 4%–10% greater for a pelvis scan.
A person who is 10 kg lighter will receive a dose that is 11%–14% greater for a chest scan and 10%–13% greater for a pelvis scan.
The differences amount to 0.7 mSv to 1.6 mSv from one scan, but since radiotherapy treatments are often given in 20–30 fractions, the increase in cumulative dose can be significant if protocols are not optimised"

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Size-specific Effective Dose (SED)

The culture of adapting imaging exposure parameters and field sizes to individual patients is less well established in IGRT than in diagnostic radiology

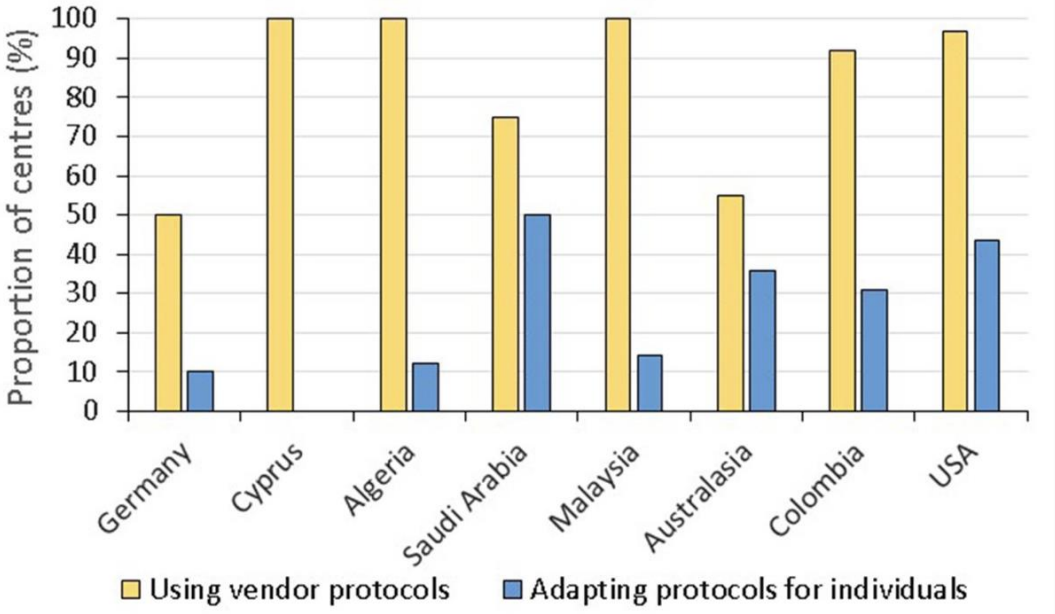

Figure 1. Bar charts showing the proportions of radiotherapy centres using vendor protocols for kV CBCT imaging and adapting CBCT protocols for individual patients in a recent survey of practices in a selection of countries [10].

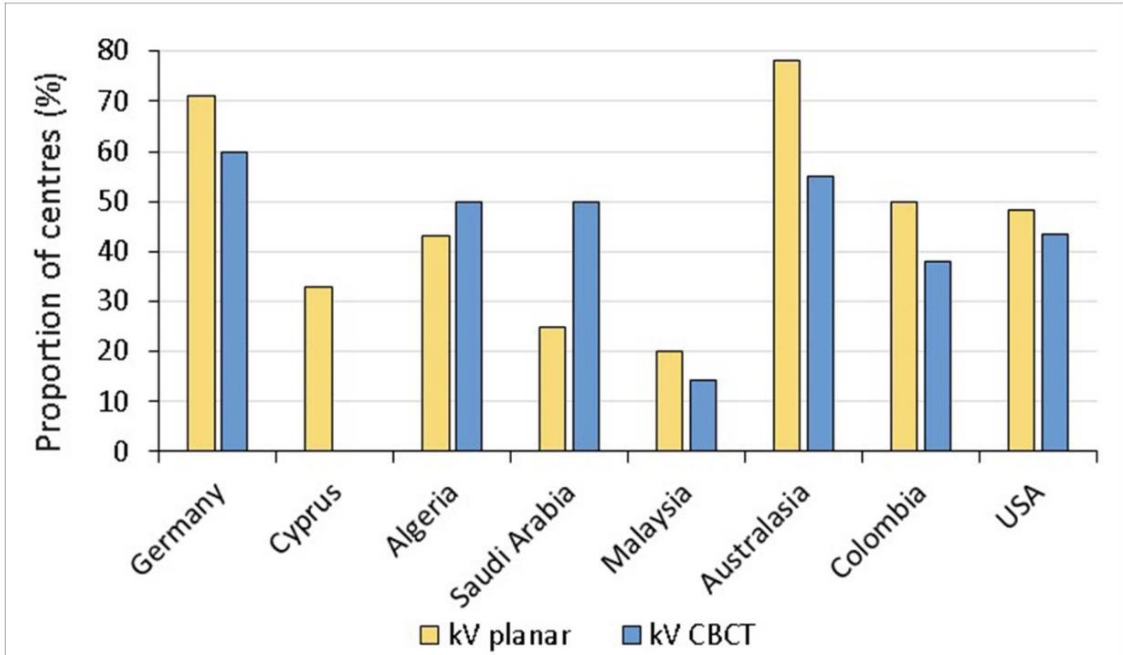

Figure 2. Bar charts showing the percentage of radiotherapy centres in different countries that adjust the field size for kV IGRT planar and kV CBCT imaging in a recent survey of imaging practices [10].

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Organ at Risk–sparing Achieved by Adaptive Radiation Therapy

Clinical Site	ART Type	No. of Patients	Clinical Implementation of ART?	Fractionation Scheme	OAR	OAR Dose Sparing
Oropharyngeal (14)	Offline	22	Yes	66–72 Gy, 30–33 fractions	Contralateral parotid	0.6 Gy or 2.8%
					Ipsilateral parotid	1.3 Gy or 3.9%
Head and neck (13)	Offline	13	No	70 Gy, 35 fractions	Parotids	3.1 Gy
Cervix (10)	Offline	9	Yes	45 Gy, 25 fractions	Rectum V95%	3.20%
					Bladder V95%	1.10%
Pancreas (35)	Online MRI-guided	36	No	40 Gy, 5 fractions	Duodenum V33 Gy	0.3 cm^3
Abdominopelvic (23)	Online MRI-guided	5	Yes		Small bowel V50 Gy (one patient)	67.8 cm^3
Adrenal (36)	Online MRI-guided	52	Some patients	24–60 Gy, 3–8 fractions	Stomach NTCP	8.70%
Bladder (26)	Online CBCT-guided	3	Yes		Bowel cavity V45 Gy	24%–30%
Prostate (15)	Online CBCT-guided	25	No	54 Gy, 27 fractions + prostate boost	Bladder D90%	13.10%
					Rectum D90%	6.50%
Abdominal oligometastatic (40)	Online CBCT-guided	8	No	50 Gy, 5 fractions	Stomach V36 Gy	0.36 cm^3
					Duodenum V36 Gy	0.96 cm^3
					Small bowel V36 Gy	1.09 cm^3
					Large bowel V36 Gy	0.8 cm^3

Note.—ART = adaptive radiation therapy, CBCT = cone-beam CT, D90% = minimum dose that 90% of the structure is receiving, NTCP = normal tissue complication probability, OAR = organ at risk, V33 Gy = volume receiving more than or equal to 33 Gy, V36 Gy = volume receiving more than or equal to 36 Gy, V45 Gy = volume receiving more than or equal to 45 Gy, V50 Gy = volume receiving more than or equal to 50 Gy, V95% = volume receiving at least 95% of the prescription dose.

: Coverage of Clinical Targets by Adaptive Radiation Therapy

Clinical Site	ART Type	No. of Patients	Clinical Implementation?	Fractionation Scheme	Target Coverage		Clinical Target Volume	
					Metric Evaluated	Change in Coverage	Metric Evaluated	Change in Volume
Oropharyngeal (14)	Offline	22	Yes	66–72 Gy, 30–33 fractions			CTV volume	−5%
Head and neck (13)	Offline	13	No	70 Gy, 35 fractions	CTV 70 D98%	+0.6%	PTV volume	No significant change
NSCLC (30)	Offline	50	Yes	45–75 Gy			CTV volume	−42%
Cervix (10)	Offline	9	Yes	45 Gy, 25 fractions	CTV coverage	Equivalent	PTV V95%	−87 cm^3
Pancreas (35)	Online MRI-guided	36	No	40 Gy, 5 fractions	GTV V95%	+1.1 Gy		
Abdominopelvic (23)	Online MRI-guided	5	Yes		PTV V95%	+14%		
Abdomen (22)	Online MRI-guided	20	Yes	50 Gy, 5 fractions	GTV V100%	+4%		
					PTV V95%	+3.2%		
Lung (38)	Online MRI-guided	50	Yes		PTV V100%	+4.4%		
Bladder (26)	Online CBCT-guided	3	Yes		PTV V95%	+11.4%	PTV volume	−42%
Prostate (15)	Online CBCT-guided	25	No	54 Gy, 27 fractions + prostate boost	CTV D98%	+2.9%		
Cervix (11)	Online CBCT-guided	13	No	45 Gy, 25 fractions + LN boost	CTV V95%	+7.9%		
Rectum (11)		15		50 Gy, 25 fractions	CTV V95%	+1.5%		
Prostate (25)	Online CBCT-guided	18	Yes	36.6 Gy, 6 fractions	PTV D99%	+6.7%		
Rectum (24)	Online CBCT-guided	12	Yes	25 Gy, 5 fractions	PTV V95%	Improved		
Abdominal oligometastatic (40)	Online CBCT-guided	8	No	50 Gy, 5 fractions	PTVopt V95%	+10.15%		

Note.—ART = adaptive radiation therapy, CBCT = cone-beam CT, CTV = clinical target volume, D98% = minimum dose that 98% of the target is receiving, D99% = minimum dose that 99% of the target is receiving, GTV = gross tumor volume, LN = lymph node, NSCLC = non–small cell lung cancer, PTV = planning target volume, PTVopt = PTV optimization structure, V95% = volume receiving at least 95% of the prescription dose, V100% = volume receiving at least 100% of the prescription dose.

Clinical Outcomes of Adaptive Radiation Therapy

Clinical Site	ART Type	No. of Patients	Fractionation Scheme	Clinical Outcome		Toxicity	
				Metric Evaluated	Outcome	Metric Evaluated	Outcome
Oropharyngeal (14)	Offline	22	66–72 Gy, 30–33 fractions	Local control Regional control	100% 95%	Comparison to IMRT	Comparable
NSCLC (30)	Offline	50	45–75 Gy	Local control Median PFS Median OS	70% 8.3 months 30.5 months	Comparison to RTOG 9410 clinical trial	Reduced
Adrenal (36)	Online MRI-guided	52	24–60 Gy, 3–8 fractions			≥ grade 3 toxicity	0%
Prostate (37)	Online MRI-guided	101	36.25 Gy, 5 fractions			≥ grade 2 early GI toxicity ≥ grade 2 early GU toxicity Comparison to HYPRO study	23.8% 5% Reduced
Lung (38)	Online MRI-guided	50		12 months, local control 12 months, OS 12 months, DFS	95.60% 88% 64%	≥ grade 2 toxicity ≥ grade 3 toxicity	30% 8%
Abdomen (22)	Online MRI-guided	20	50 Gy, 5 fractions	6 months, PFS 12 months, OS	89.10% 75%	≥ grade 3 acute toxicity	0%

Note.—ART = adaptive radiation therapy, DFS = disease-free survival, GI = gastrointestinal, GU = genitourinary, HYPRO = hypofractionated versus conventionally fractionated RT for patients with localized prostate cancer, IMRT = intensity-modulated RT, NSCLC = non–small cell lung cancer, OS = overall survival, PFS = progression-free survival, RTOG = Radiation Therapy Oncology Group.

To conclude (1):

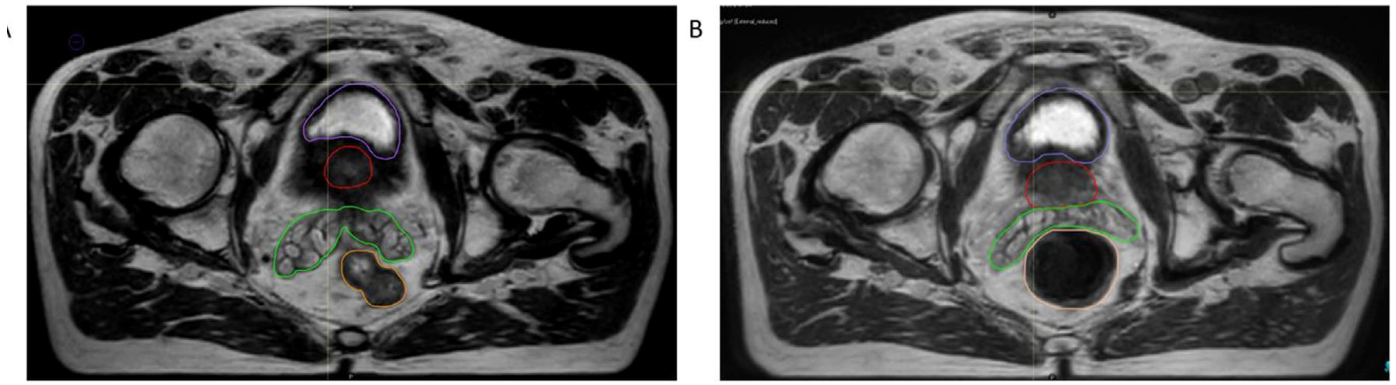
A few dosimetric evaluations are available in the literature regarding the contribution of CT scanning for ART to the dose received by the patient.

These doses are in general negligible when compared with the advantages of ART in terms of OAR sparing, better PTV coverage and reduction of the PTV volume.

The dose received because of ART by the patient varies with the target of the treatment and the PTV volume. Lighter and shorter people may receive higher doses by cone beam scanning and specific protocols may help to further reduce the dose received for them.

Is there a future?

Probably the MR-ART can be the future



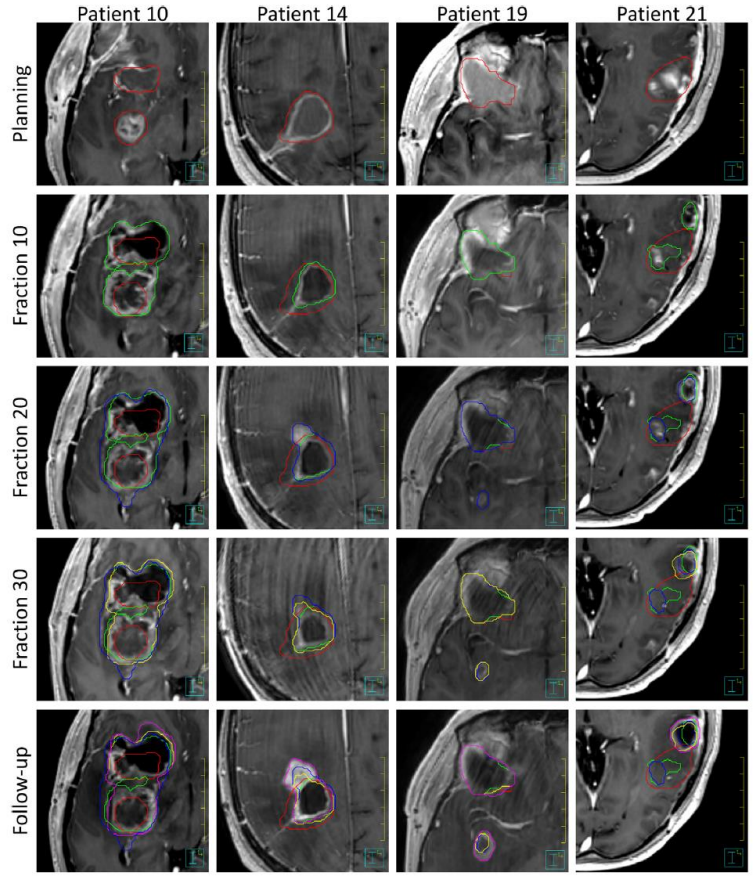
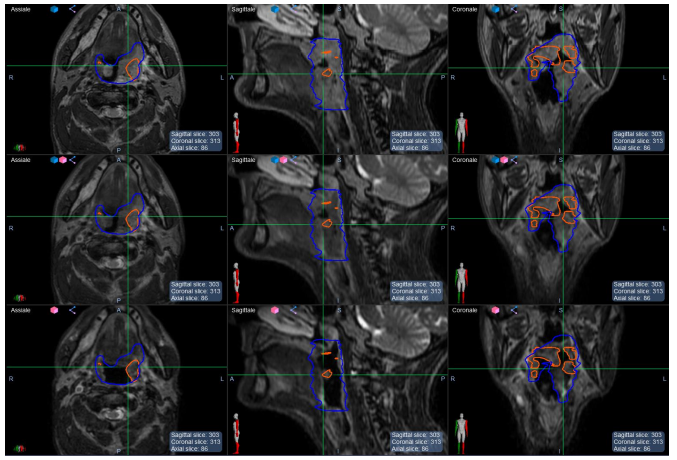


Table 4: Comparison between MRI-based and CBCT-based Online Adaptive Radiation Therapy Approaches

Feature	MR-linac Online ART	CBCT-based Online ART
Image quality	Superior (46)	Inferior image quality and soft-tissue definition (6,20,33,46,47)
Image artifacts	Susceptibility, motion, distortion (6)	Hardening, motion, scatter, ring, aliasing, misalignment (20,33,49)
Inaccuracies in determining size of target	NA	Cervix, prostate (57,58)
Information about physiologic characteristics of tissue (eg, diffusion, perfusion)	Superior	NA
Functional or quantitative imaging	Possible; not yet ready for clinical implementation (6,16)	NA
Limited field of view	Limited to 50 cm (6)	Limited to 16 cm in the longitudinal direction (6,55)
Image acquisition time	Longer (limited sequences within 2 min) (46)	Shorter (within 1–2 min) (46)
Conversion of image-of-the-day to electron density map	Synthetic CT; bulk density assignment to anatomic structures; multimodality DIR (6,16)	Conversion to Hounsfield units via DIR, CBCT calibration curves, dose deformation* (33,52)
Imaging-related radiation exposure	None	Up to 10 cGy per scan; typically, 0.2 cGy–2 cGy (6,20,29,46,56)
Continuous imaging (eg, motion gating, real-time tracking of dose accumulation)	Possible (6)	Limited by radiation exposure
Specialized training for MRI-based RT planning	Required (46)	NA
Radiation and MRI-compatible facilities	Required (46)	NA
Cost of linear accelerator, structural investment	Very high (46)	Reduced compared with MRI (46)
Limits on patient size	More restrictive (46)	Less restrictive (46)
Contraindications (claustrophobia, metallic implants)	Yes (46)	No (46)



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Treatment duration	Longer (21,22,46)	Potentially shorter (11,26,27)
Electron return effect†	Significant‡	NA
Significant geometric distortion	Due to magnetic-field gradient nonlinearities, field inhomogeneities§	NA
Patient-dependent geometric distortions‖	Possibly significant	NA

Note.—ART = adaptive radiation therapy, CBCT = cone-beam CT, DIR = deformable image registration, MR-linac = MRI-linear accelerator, NA = not applicable.

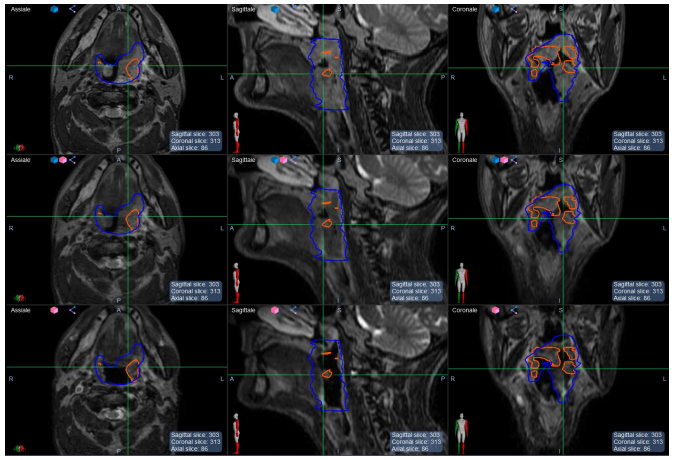
* Poorer image quality of CBCT images can lead to dose calculation inaccuracies.

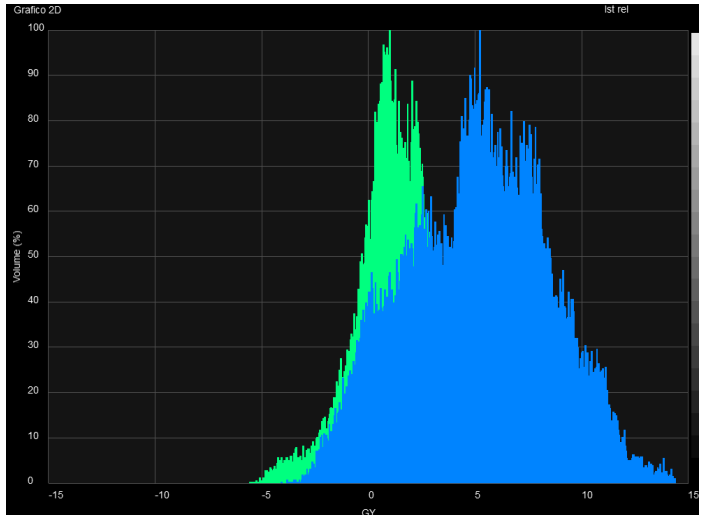
† The electron return effect refers to electron path distortion and increase in radiation dose delivery near air-tissue interfaces.

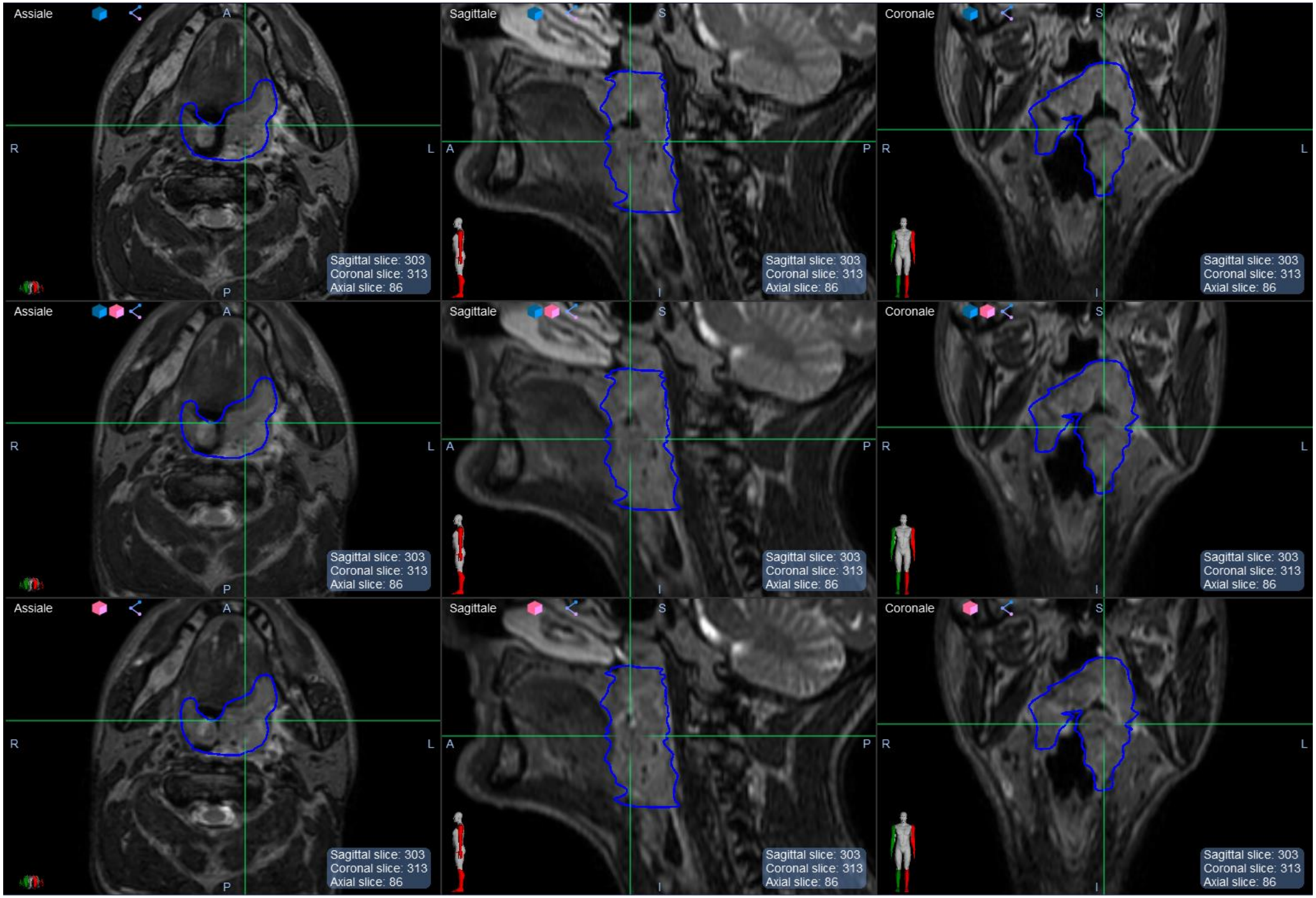
‡ The electron return effect with MRI can be addressed with Monte Carlo algorithms and multiple fields.

§ MRI geometric distortion can be accounted for by image processing algorithms.

‖ Patient-dependent geometric distortions result from local magnetic field inhomogeneities.

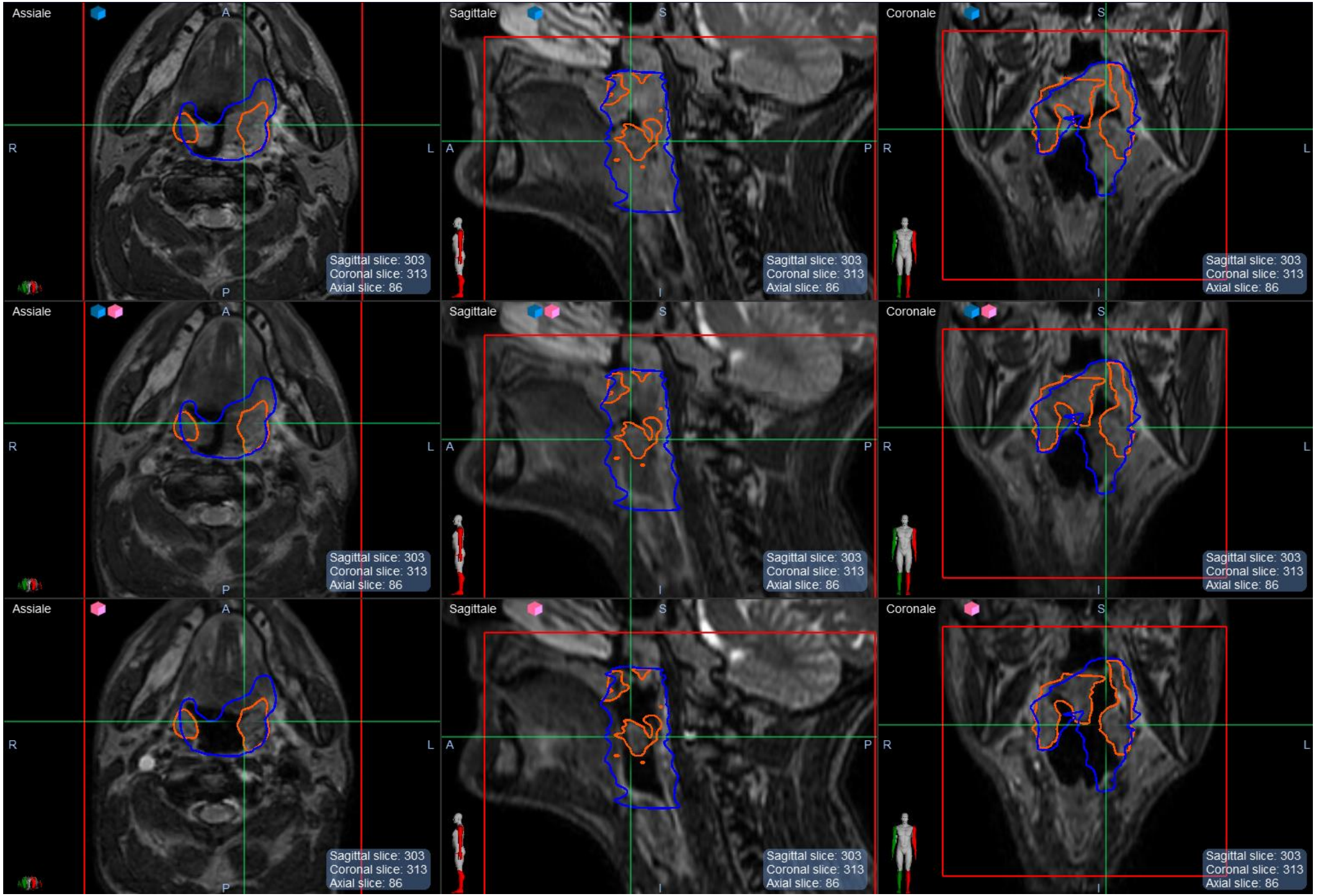





Assiale
Sagittale
Coronale
Sagittal slice: 303
Coronal slice: 313
Axial slice: 86

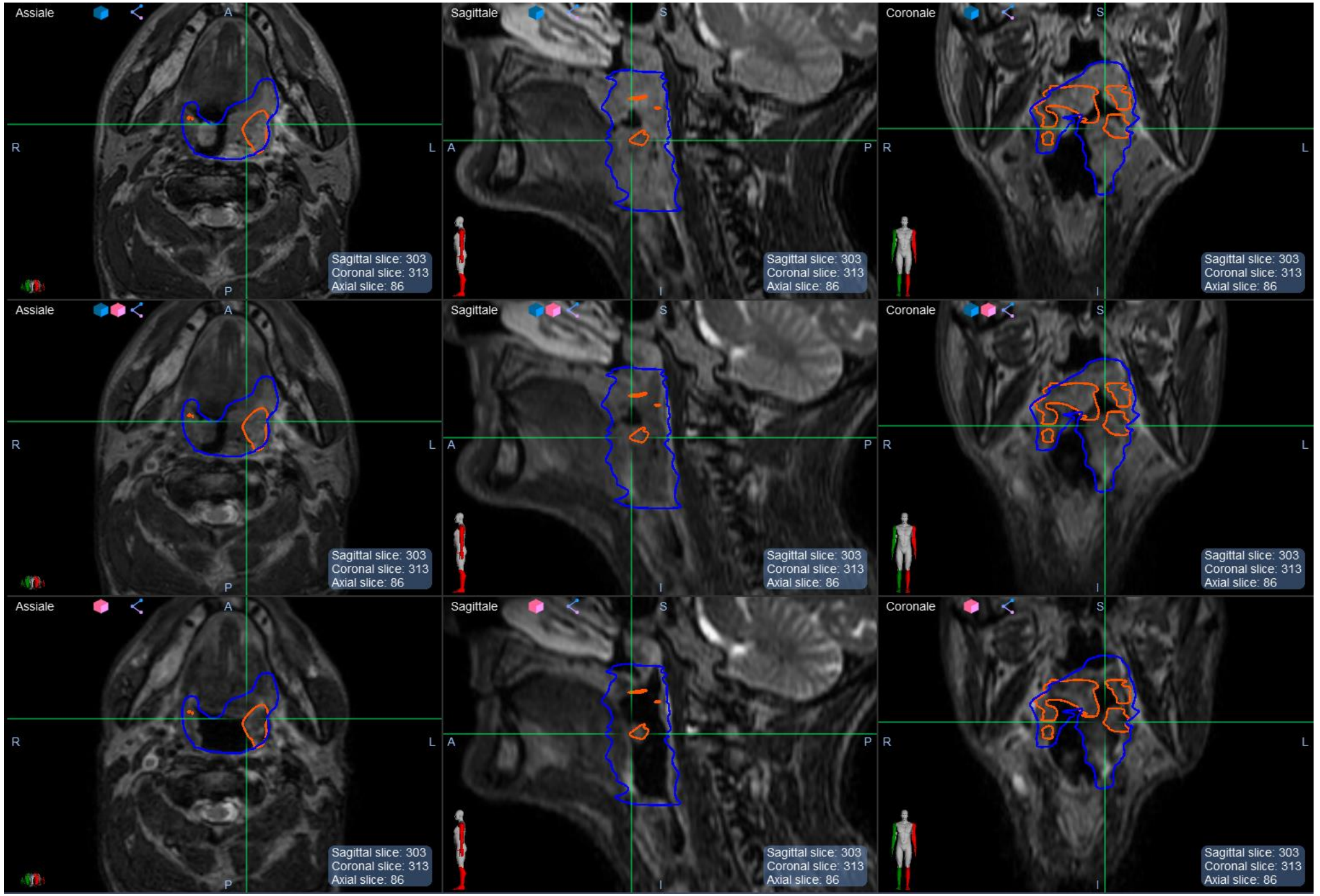
reference

1



reference

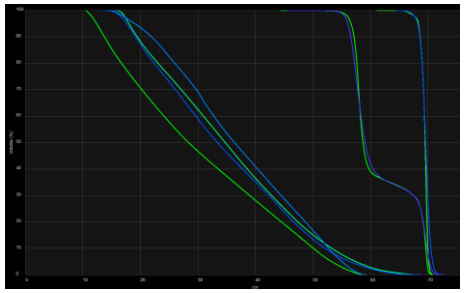
16

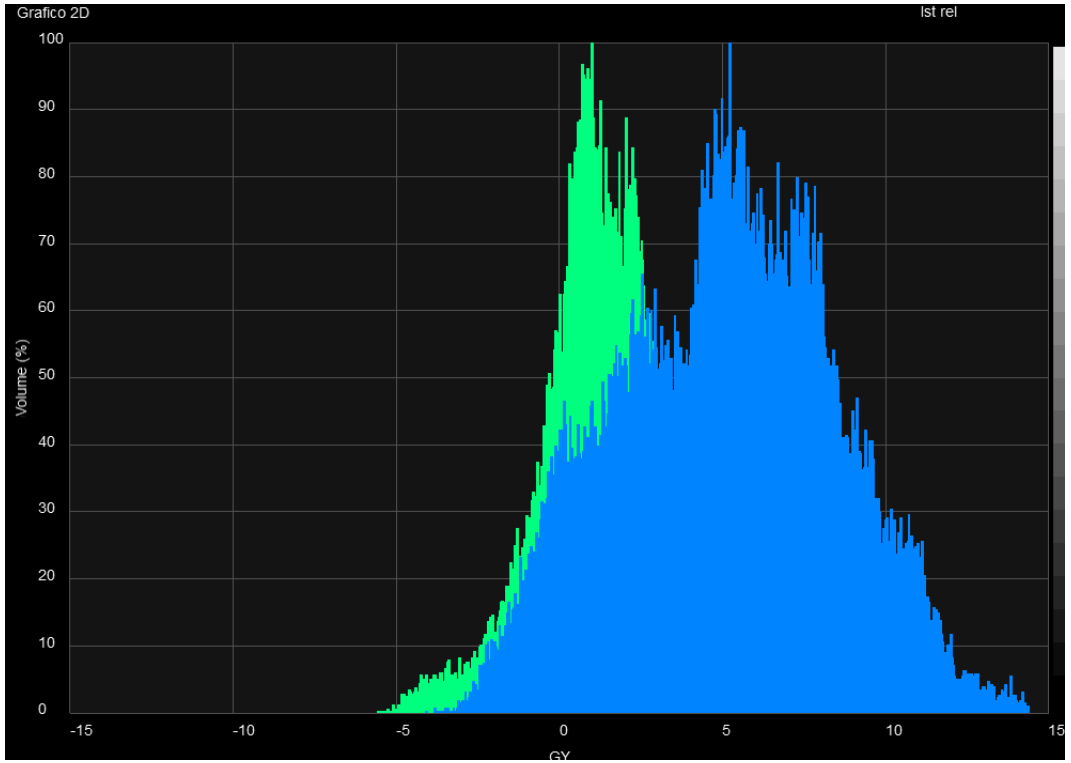


reference

24

H&N dose accumulation





Dose difference relative Volume Histogram
Parotids
Right (blue) - left (green)
If D>0 previsional dose > accumulated dose

Conclusions

- Adaptive RT: very useful, almost crucial, in a precise radiotherapy process

- On-line and off-line ART using cone-beam CT is much more common and can be easily used in all RT centres

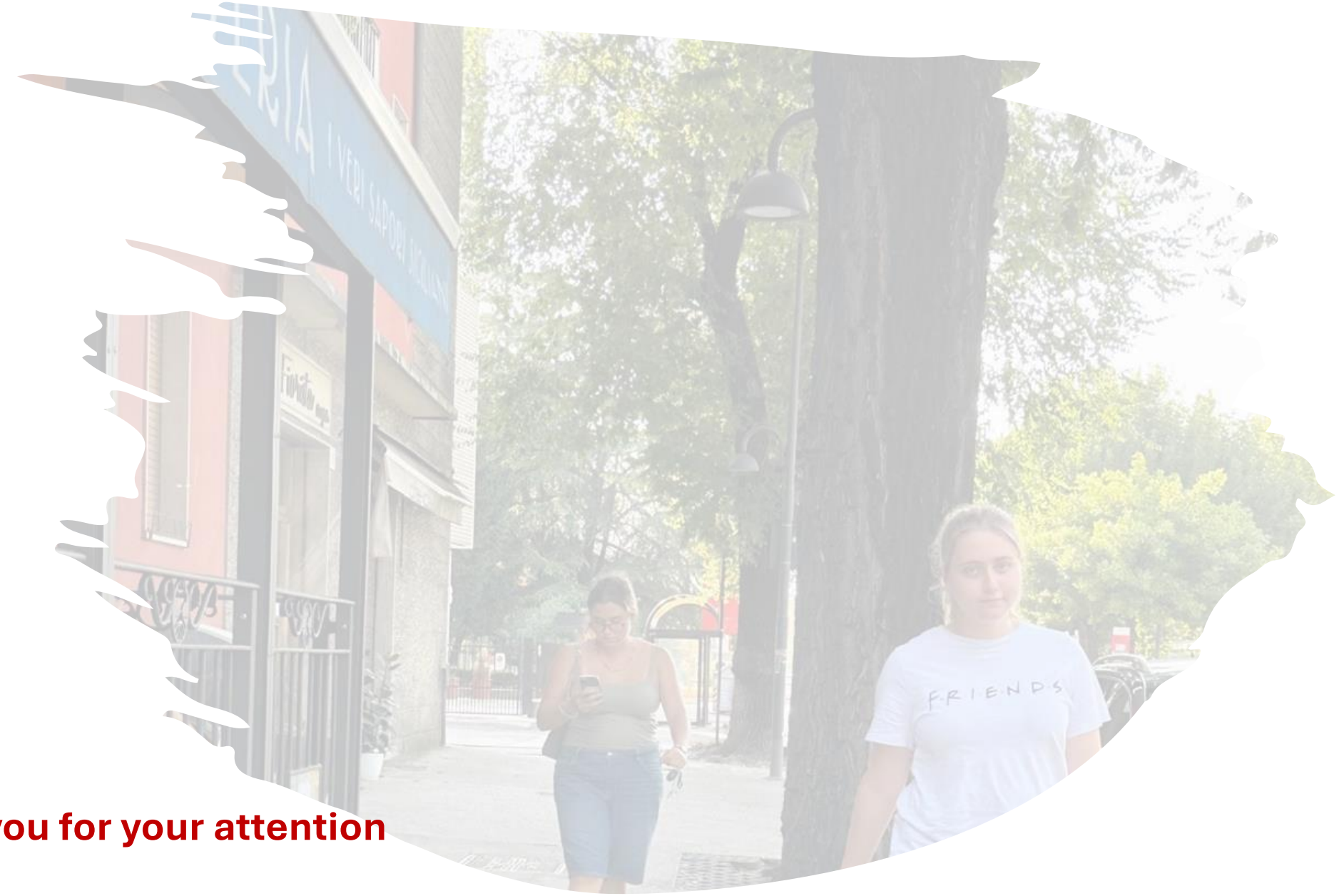
- Even if it is true that in patients treated with RT, the doses required for ART procedures are very low, it is also true that the ALARA principle has to be adopted for each patient and optimization procedures should be much more diffused than now

Conclusion 2. Attention for the future

- Procedures of deformable image registration and dose accumulation are the key passages to obtain best dosimetric results by ART;

- ART with MRI will consent better target and OAR identification, non-invasive knowledge of tumour biology and can be used better personalize the treatment and the delivered dose

- Prospective studies integrating all these aspect are necessary to confirm the still embryonal data



Thank you for your attention