SYSUCC
SINCE 1964
中山大學
肿瘤防治中心
SUN YAT-SEN UNIVERSITY CANCER CENTER

Deep learning-based 3D in vivo dose reconstruction with EPID for magnetic resonance-linear accelerators

Yongbao Li, PhD

Sun Yat-sen University Cancer Center
Guangzhou, China

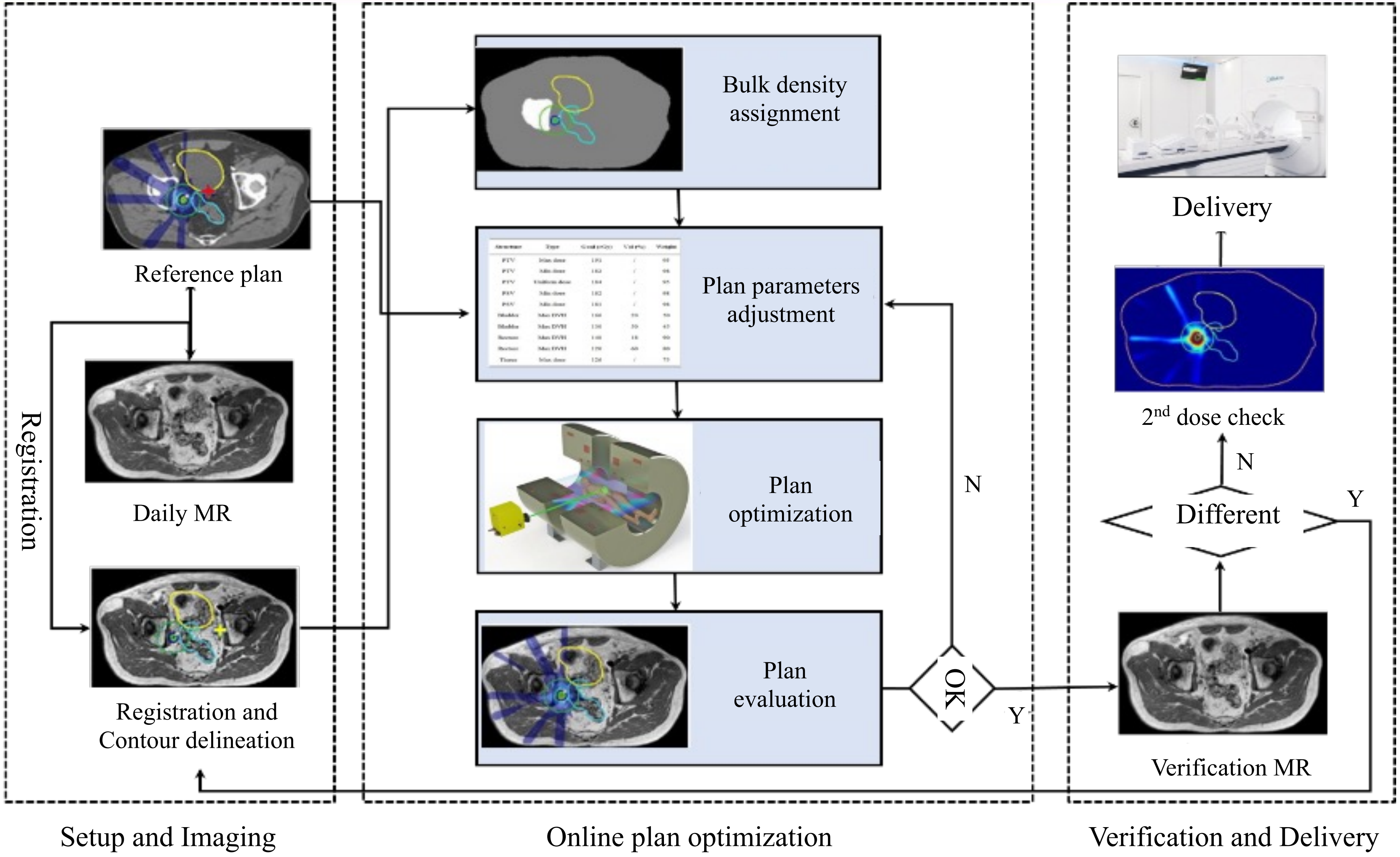
2024.06.07

創新 敬業 友愛 诚實

Background

- MR-Linac
  - High soft-tissue contrast
  - No imaging dose
  - Imaging at different temporal scales
  - Functional imaging
- Adaptive radiotherapy
  - Online ART
  - Real-time ART
  - Biology guided ART

Online ART workflow



Patient specific quality assurance (QA) for MR-Linac

- Measurement based QA for reference plan (Used in clinic)
  - Reference plan is not delivered
  - Patient modeling and dose calculation is not included

- Independent dose check for adaptive plan (Used in clinic)
  - No delivery information is included

- EPID-based in vivo dosimetry (Desired in clinic)
  - End-to-end dose verification, including verification of patient geometry and setup, synthetic CT generation or density assignment, dose calculation from TPS, plan transfer and delivery
  - Real-time dose monitoring

Unity EPID

SAD = 143.5 cm

SDD = 263.5 cm

Scale factor = 1.84

EPID size： 41 cm × 41 cm

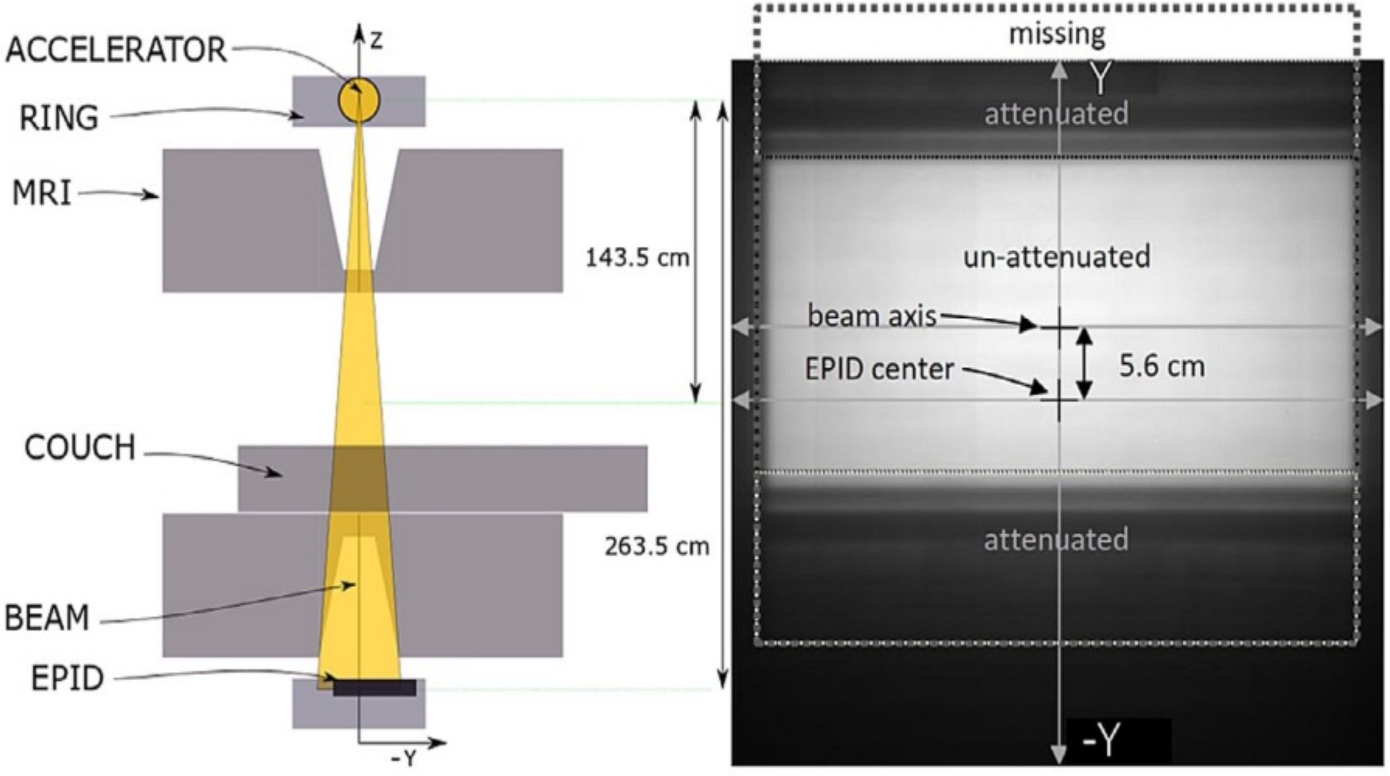
Dimension： 1024 × 1024

Resolution： 0.4 mm × 0.4 mm

Unattenuated region：

X: [-11 cm, 11 cm]

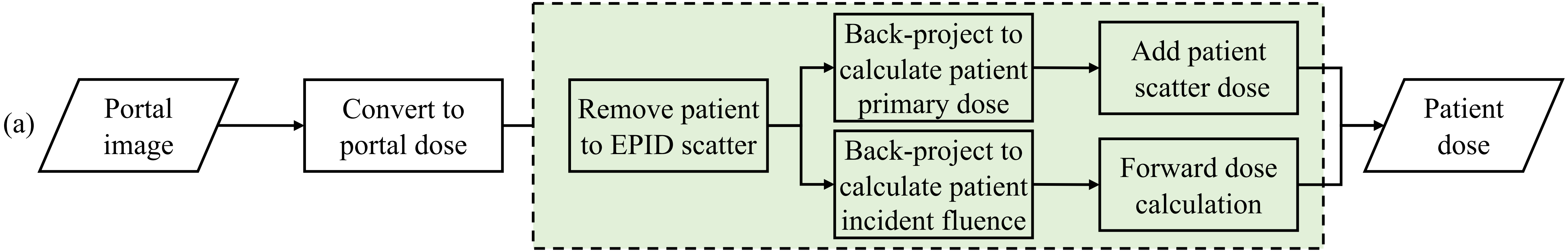
Y: [-4.8 cm, 4.8 cm]



(a) (b)

Torres-Xirau I, Olaciregui-Ruiz I, van der Heide UA, Mans A. Two-dimensional EPID dosimetry for an MR-LINAC: Proof of concept. Med Phys. 2019;46:4193-4203.

Conventional in vivo dose reconstruction workflow



- Back projection algorithm is not accurate for inhomogeneous region, magnetic field effect can not be considered
- Forward calculation with Monte Carlo has low efficiency, is challenged for real-time dose monitoring

Accuracy of BP algorithm in low density region

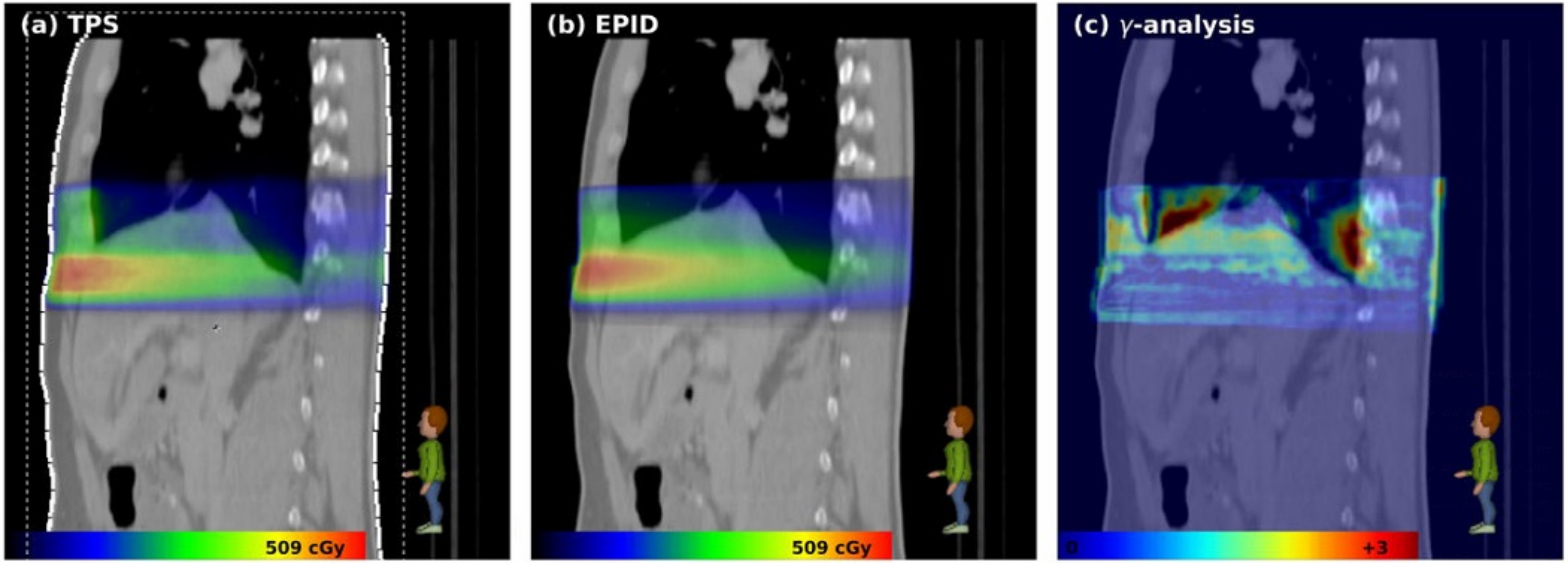
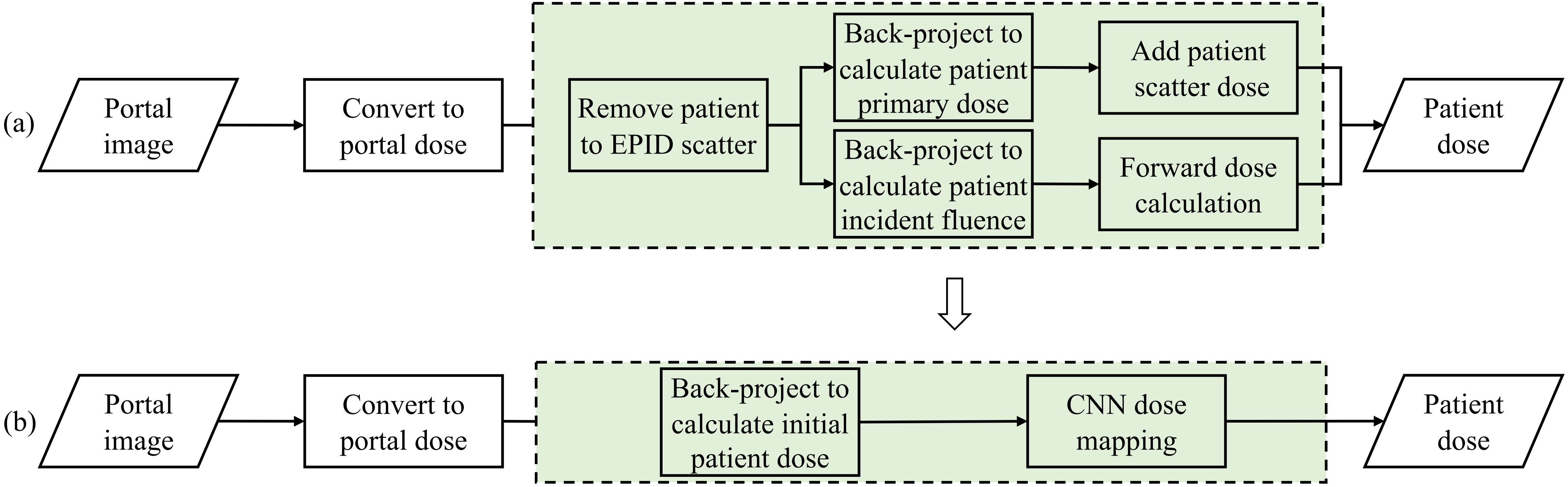


Fig. 4. (a) TPS dose, (b) *in vivo* EPID dose and (c) γ distributions corresponding to the field delivered at gantry angle 0° of the liver plan with the worst agreement. The agreement worsens for the parts of the beam traversing low density lung tissue.

Olaciregui-Ruiz I, et al. Automatic dosimetric verification of online adapted plans on the Unity MR-Linac using 3D EPID dosimetry. Radiotherapy and Oncology, 2021, 157: 241-246.

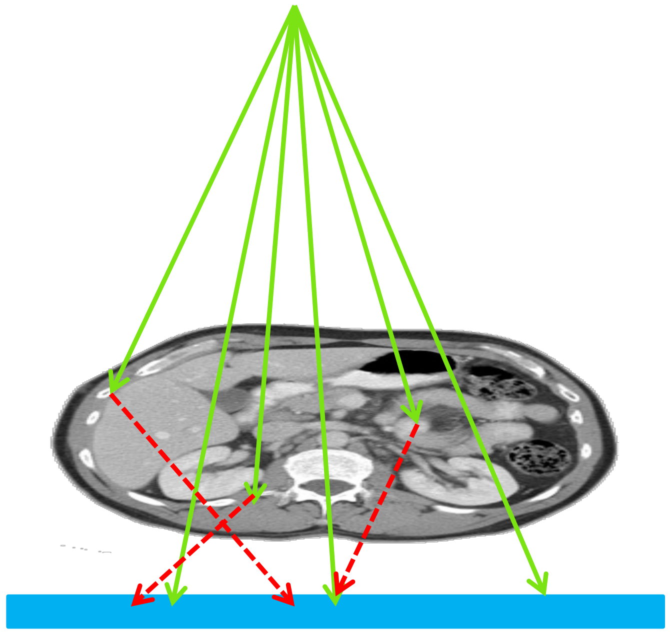
Deep learning-based 3D in vivo dose reconstruction



- No complex patient scatter modeling and commissioning step is needed
- All scatter effects, beam hardening effects, heterogeneity effects, and magnetic field-induced EREs were assumed to be captured by the CNN model

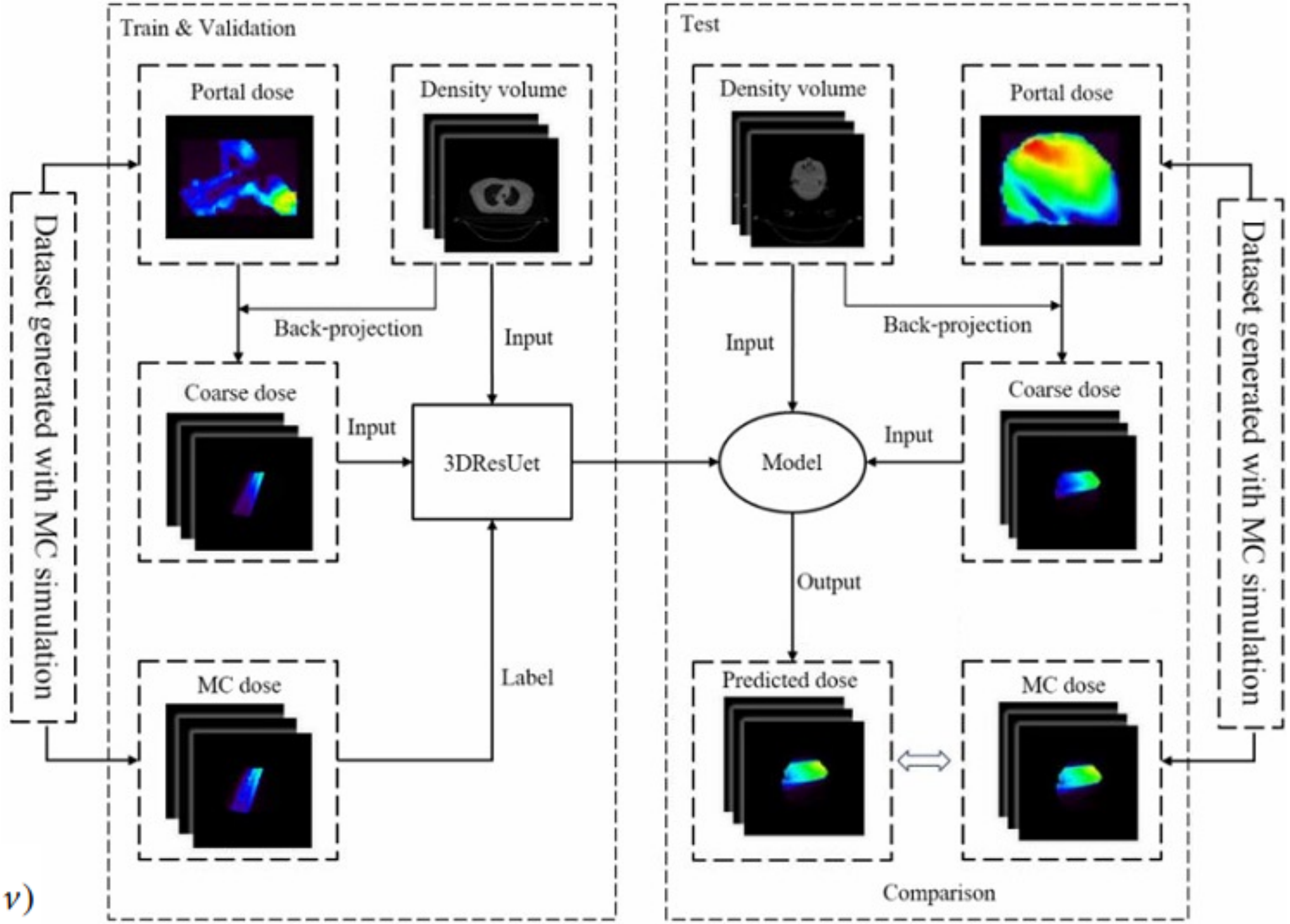
Deep learning-based 3D in vivo dose reconstruction

- Use Monte Carlo simulation to acquire 3D patient dose and 2D portal dose simultaneously



- Back projection to get coarse dose

$$d^{ini}(u, v, r) = (e^{-\mu\hat{r}} - e^{-\beta\hat{r}})/(e^{-\mu\hat{r}_{EPID}} - e^{-\beta\hat{r}_{EPID}})\frac{r_{EPID}^{2}}{r^{2}}\varphi(u, v)$$



Monte Carlo simulation with magnetic field

- gDPM —— developed by Xun Jia (JHU)
  - Based on fast MC code-DPM
  - GPU acceleration
  - Separate photon and electron transportation
  - ~60-80 times efficiency improvement with CPU version
- Extend charged particle transportation in magnetic field
  - First order approximation

$$\Delta \boldsymbol{u} = \frac{q \cdot s}{m_0 \gamma v_0^2}[\boldsymbol{v_0} \times \boldsymbol{B_0}]$$

$$\boldsymbol{u}(s) = \boldsymbol{u}_0 + \Delta \boldsymbol{u}$$

$$R = \frac{m_0 \gamma v_0^2}{q|\boldsymbol{v_0} \times \boldsymbol{B_0}|}$$

$$\delta = \frac{s}{R} \ll 1$$

$$\Delta \boldsymbol{u} = \frac{s}{R}\frac{\boldsymbol{u_0} \times \widehat{\boldsymbol{B}}_{\boldsymbol{0}}}{|\boldsymbol{u_0} \times \widehat{\boldsymbol{B}}_{\boldsymbol{0}}|}$$

$$s = \min(R \cdot \delta, s_{vox}, s_{hard}, s_{ele})$$

Xun Jia, et al. *Phys. Med. Biol.* 2011.

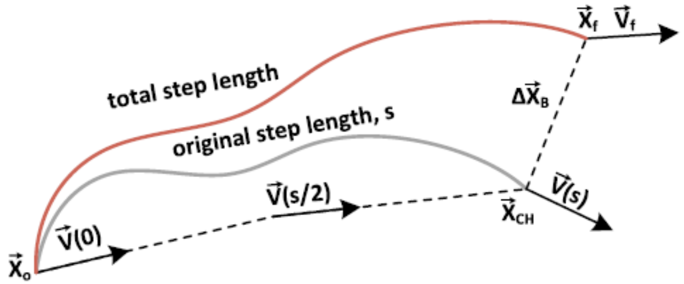
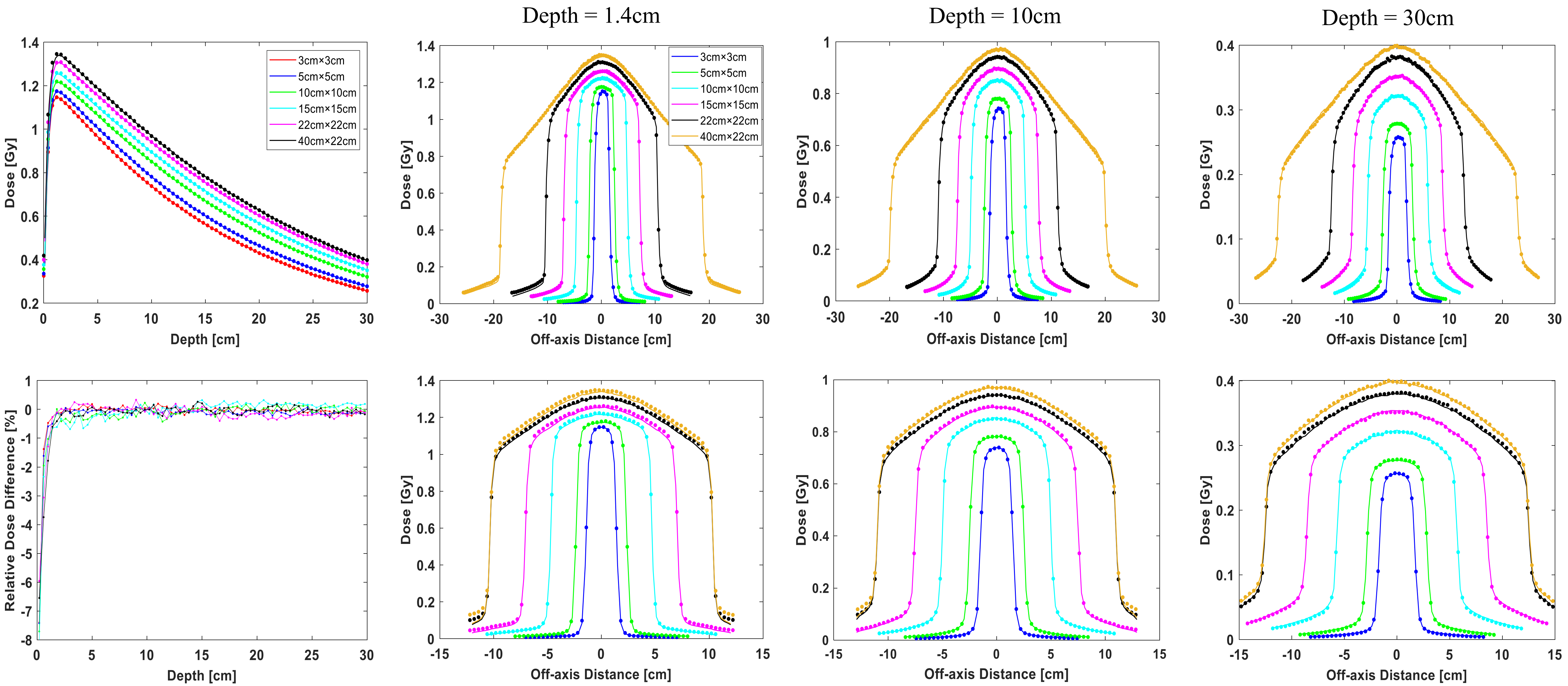


FIG. 1. Simplified EGSnrc PRESTA-II step in the presence of a magnetic field. The particle is initially at $\vec{x}_o$ with velocity $\vec{v}(0)$, it is then transported a step length, s, to $\vec{x}_{CH}$ by the CH algorithm which samples direction of motion at an intermediate, $\vec{v}(s/2)$, and final, $\vec{v}(s)$. $\Delta\vec{x}_B$ and $\Delta\vec{u}_B$ are calculated using Eqs. (2) and (6) to obtain the final position, $\vec{x}_f$, and velocity, $\vec{v}_f$.

EGSnrc Manual.

Li et al. *Med. Phys.* 2021(48).

Monte Carlo beam modeling for Unity with 1.5T



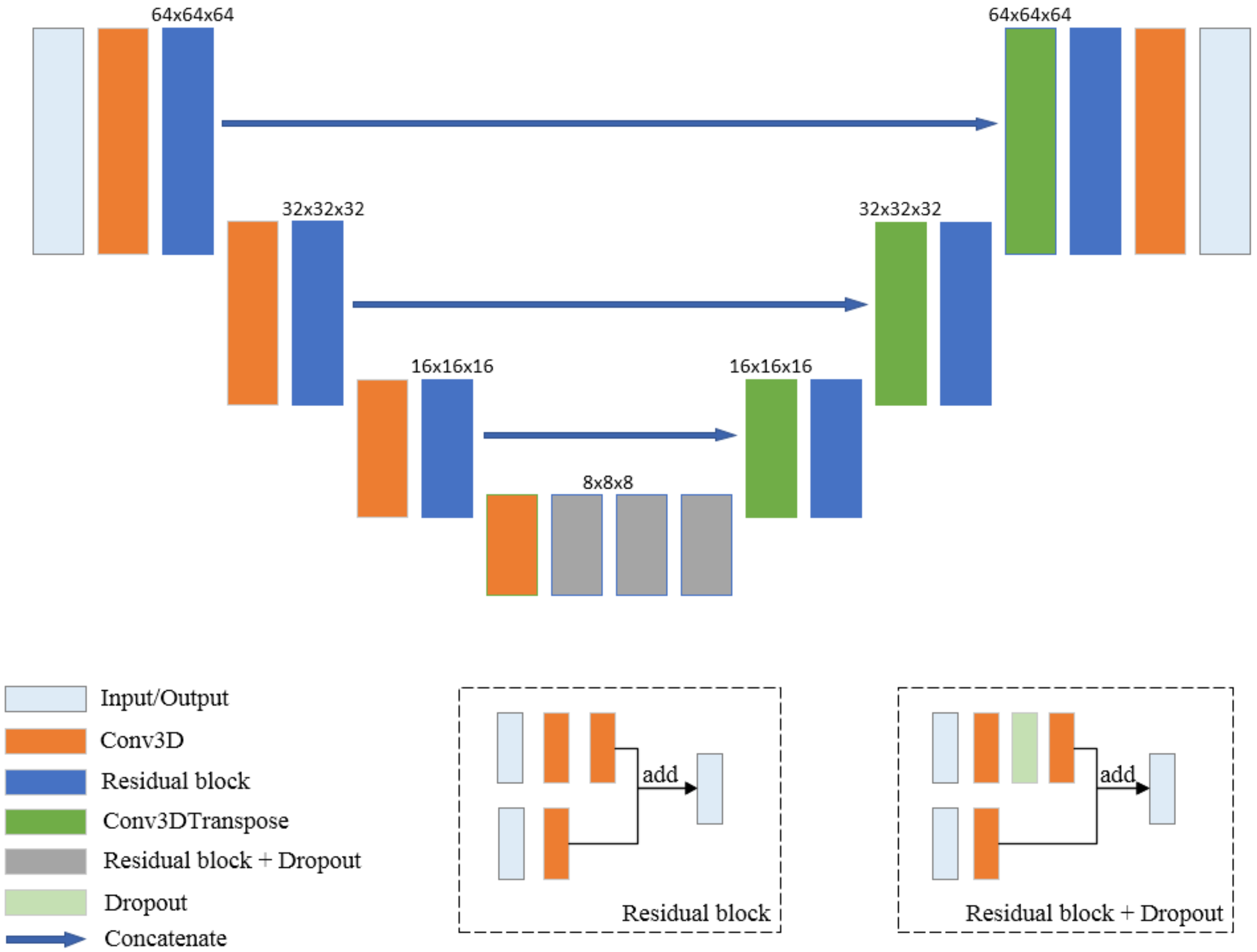
Li et al. *Med. Phys*. 2021(48).

Dataset and augmentation

- Dataset
  - 21 brain cases, 46 NPC cases, 15 lung cases, 14 rectum cases
  - training and validation set (78 cases), test set (18 cases)
  - 576 original treatment beams

- Augmentation
  - rotate the original beam angles by 10°–15° for 2–3 times
  - 1841 and 121 beams for training and validation
  - all volume dose and portal dose were recalculated for each beam

Network structure



Dose reconstruction result

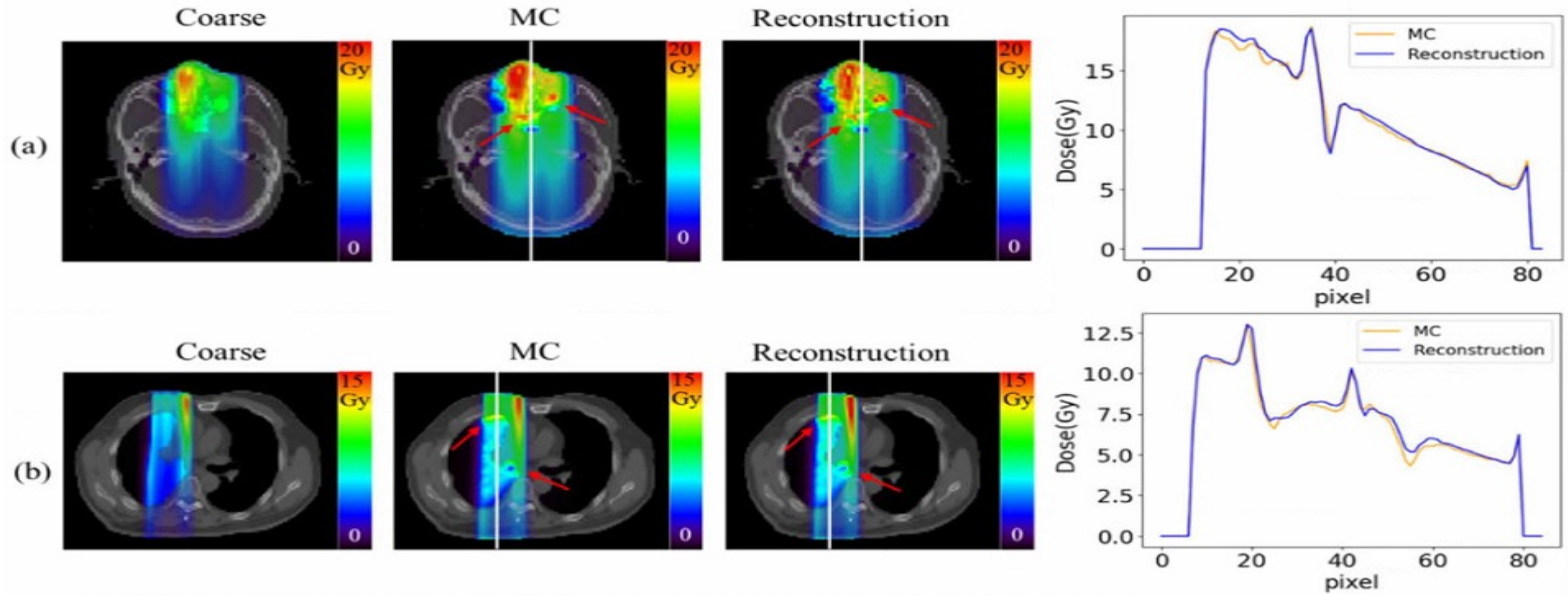
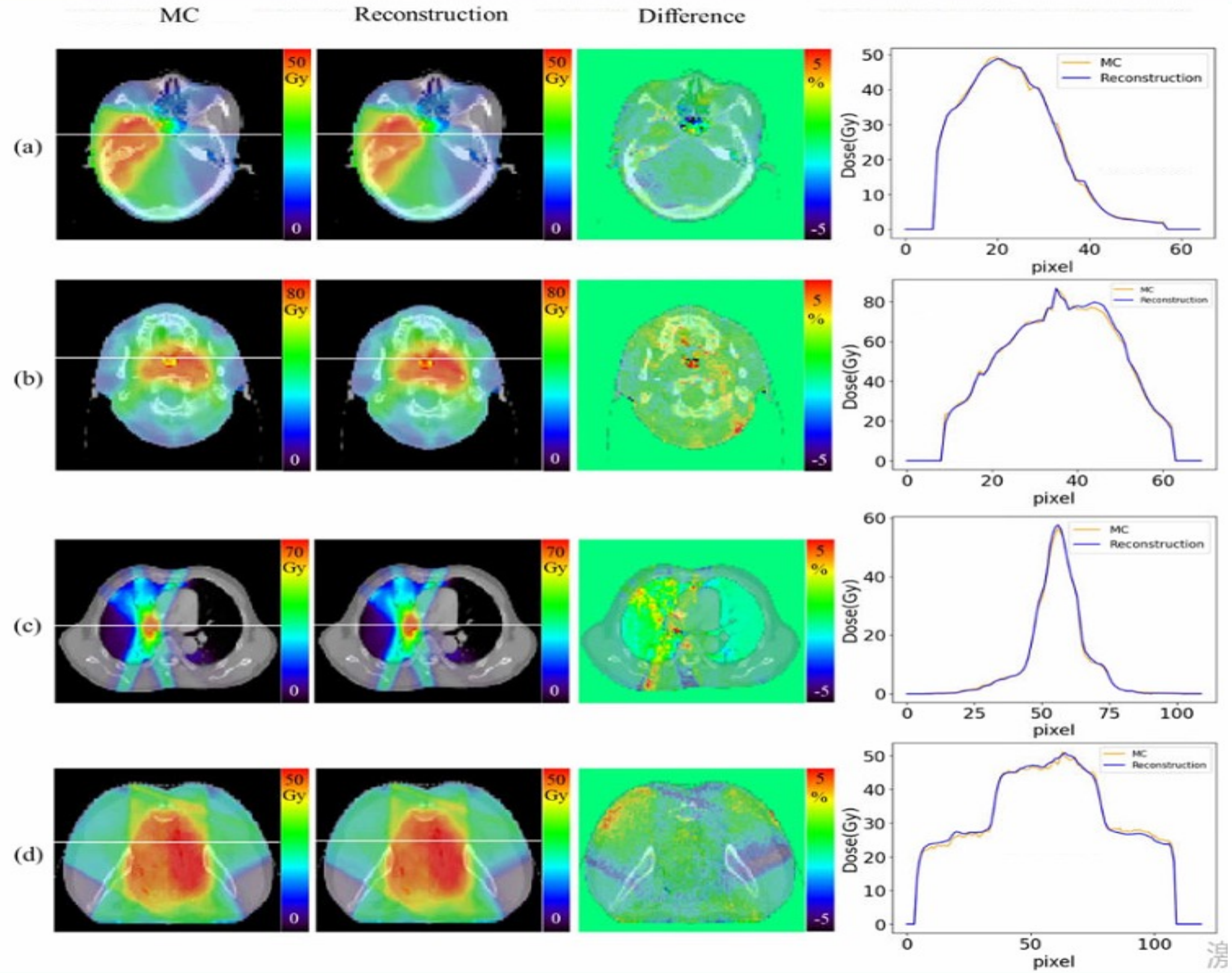


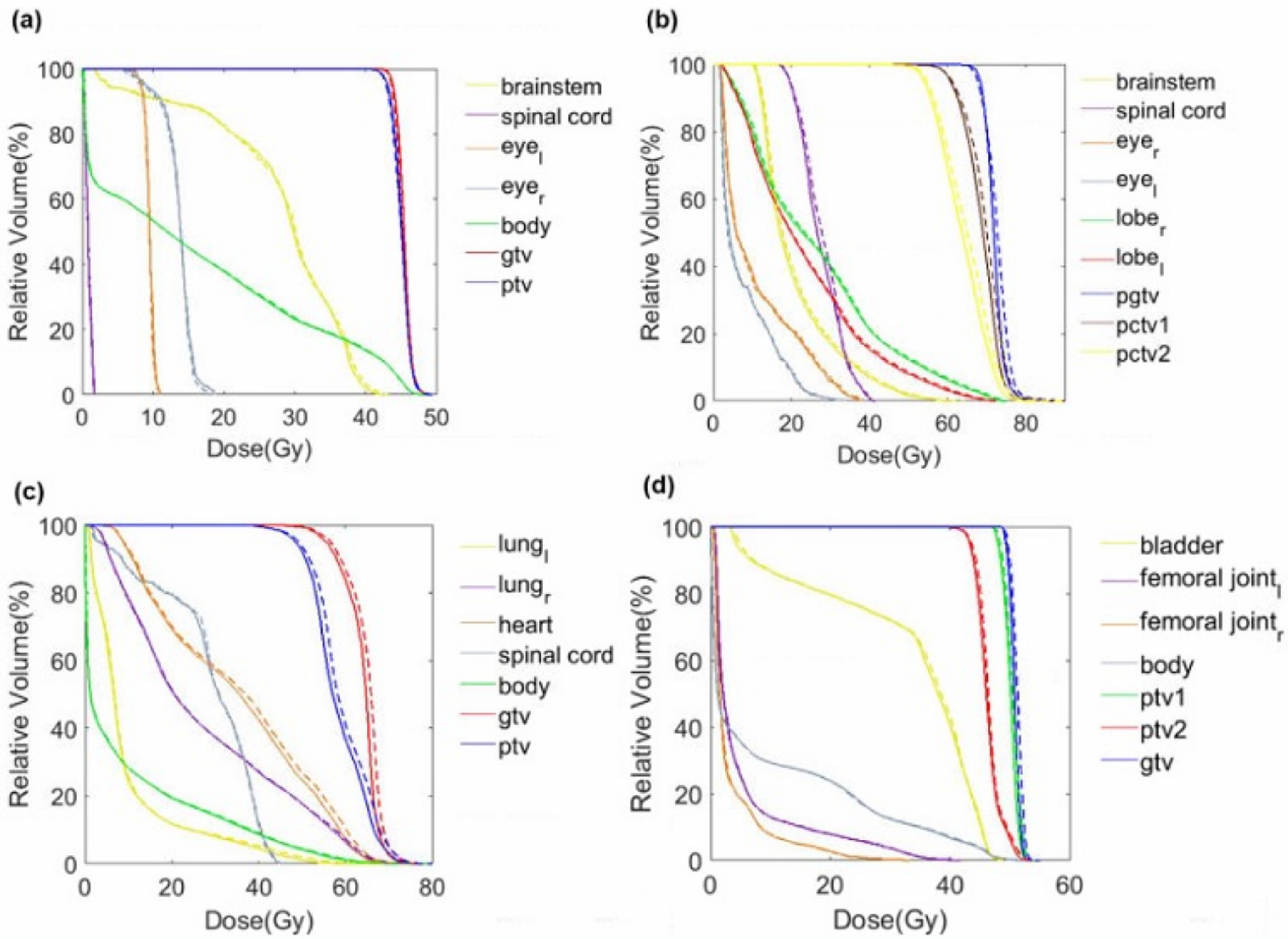
Table 1. Averaged γ-pass rates and MAE parameters for 18 tested patients (mean ± SD).

Site		Brian (4)	nasopharynx (8)	Lung (3)	Rectum (3)
γ-pass (%)	Dose > 0%, 3%/2 mm	97.42 ± 2.66	98.53 ± 0.95	99.41 ± 0.46	98.63 ± 1.01
	Dose>20%, 3%/2 mm	95.48 ± 3.31	97.20 ± 1.42	95.35 ± 0.57	95.29 ± 2.89
	Dose>50%, 3%/2 mm	94.32 ± 3.77	95.10 ± 2.01	90.40 ± 2.71	95.83 ± 1.56
	Dose > 0%, 2%/2 mm	94.02 ± 6.21	96.46 ± 1.93	98.72 ± 0.88	96.72 ± 1.73
MAE (%)	0.82 ± 0.36	0.88 ± 0.21	0.41 ± 0.19	0.67 ± 0.09	

Dose reconstruction result



Dose reconstruction result



Conclusion

- Proposed a CNN-based 3D in vivo dose reconstruction method
  - Physical processes were learned through accurate MC data-driven model training
  - Simplicity in dose reconstruction and model commission
  - Training data can be generated with clinic TPS by adding a virtual EPID structure
- Limitations
  - No validation was conducted for real measured EPID images
  - Field truncation by real EPID was not considered

Thanks !