AI-assisted target volume definition in radiation therapy

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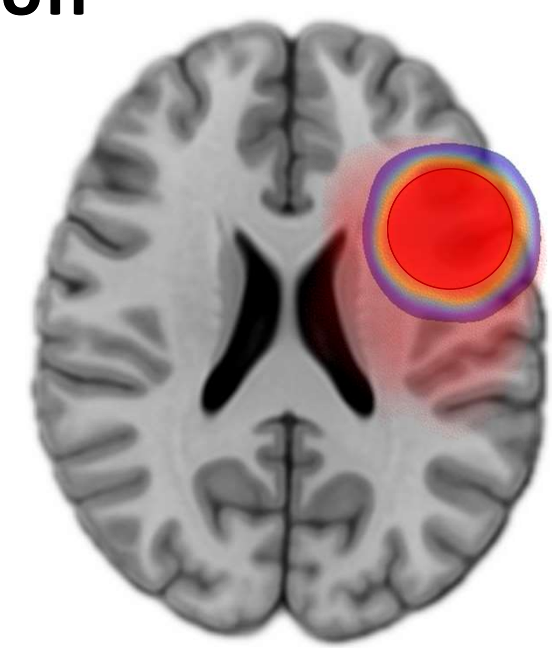
Agenda: AI-assisted Target Volume Definition

AI-assisted target volume definition in radiation therapy?

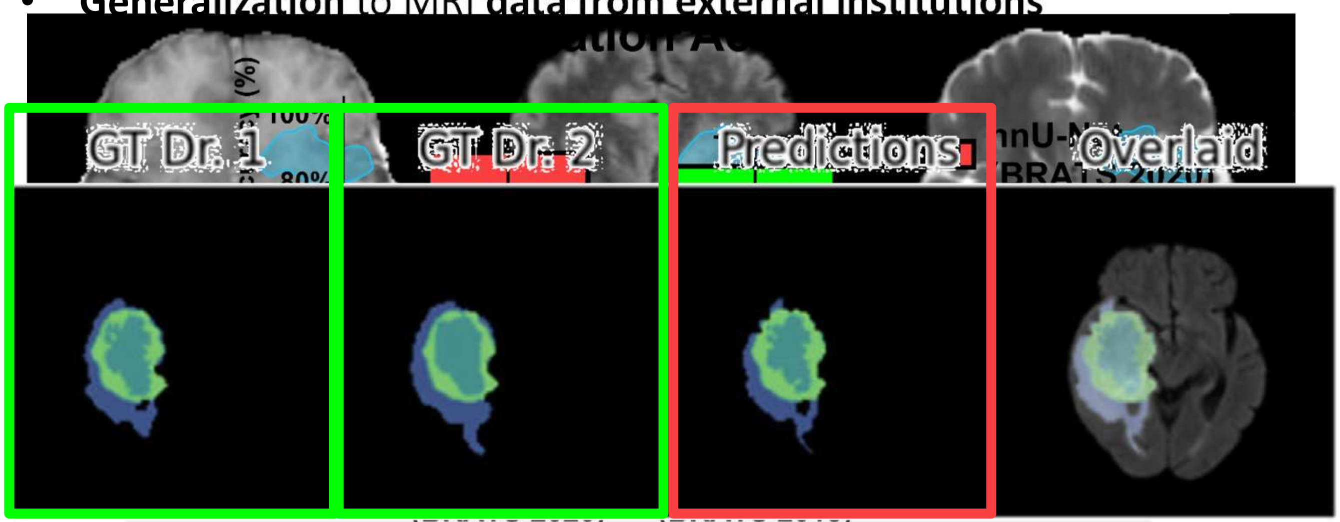
1) Deep learning tumor auto-segmentation
2) Automated CTV creation
3) AI-interactive target volume creation
4) Tumor growth &
   tumor infiltration prediction

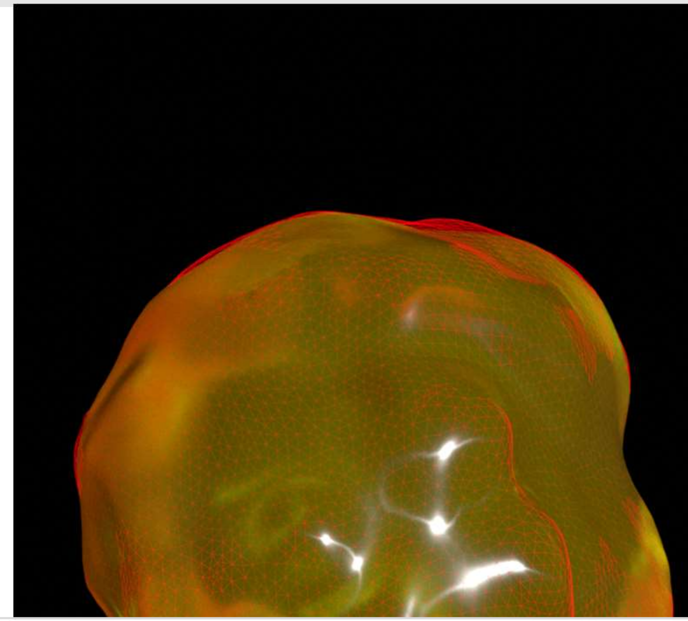


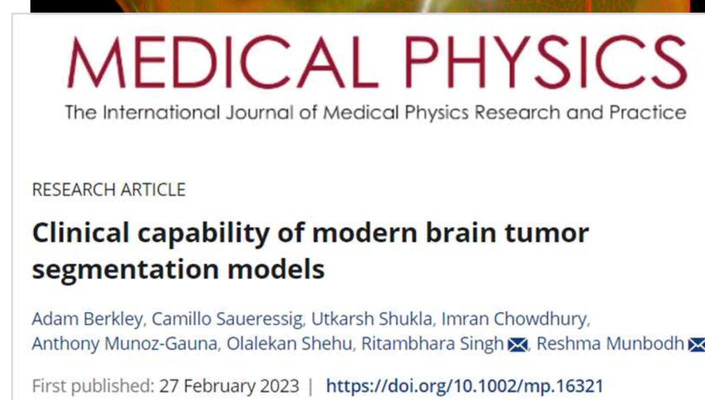
1) Deep learning tumor auto-segmentation

Deep learning brain tumor auto-segmentation:

- **3D U-Nets** demonstrate **high accuracy** for **automatic tumor segmentation** in **multimodal 3D imaging data**.
- **Differentiation** between **different tumor compartments \ classes** (e.g., necrosis, edema, contrast-enhancing tumor)
- **Accuracy** within the **range of inter-expert variability** (Menze 2014)
- **Generalization** to MRI data from external institutions






MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

RESEARCH ARTICLE

Clinical capability of modern brain tumor segmentation models

Adam Berkley, Camillo Saueressig, Utkarsh Shukla, Imran Chowdhury, Anthony Munoz-Gauna, Olalekan Shehu, Ritambhara Singh, Reshma Munbodh

First published: 27 February 2023 | https://doi.org/10.1002/mp.16321

1) Deep learning tumor auto-segmentation

Clinical benefit of AI tumor auto-contouring as a support system:

n = 5 brain metastases, n = 3 meningiomas, n = 2 vestibular schwannomas

- **Improved detection rate:** **91.3%** vs. **82.6%**, $p = 0.030$
- **Improved inter-expert variability:** Dice Score **0.90** vs. **0.86**
- **Improved contouring accuracy:** Dice Score **0.865** vs. **0.847**
- **Time savings** of **30.8%**

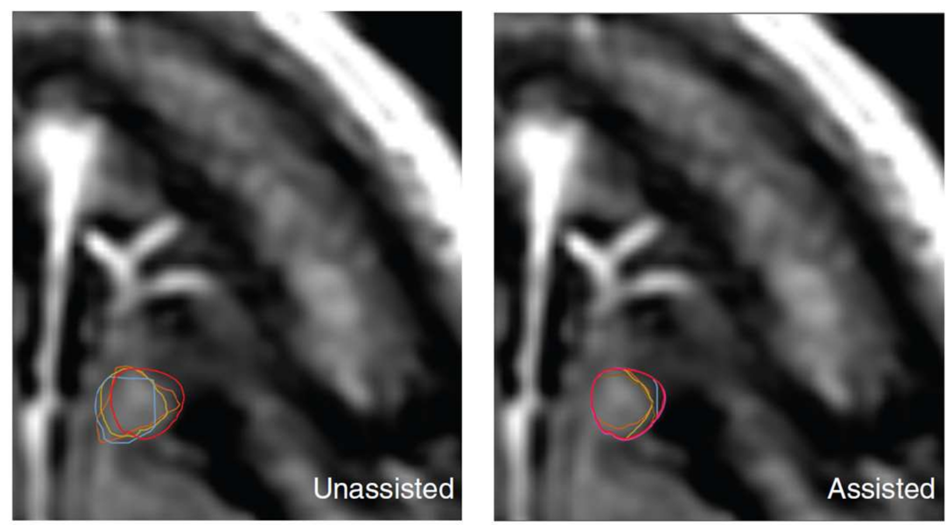
1560

Neuro-Oncology

23(9), 1560–1568, 2021 | doi:10.1093/neuonc/noab071 | Advance Access date 22 March 2021

Randomized multi-reader evaluation of automated detection and segmentation of brain tumors in stereotactic radiosurgery with deep neural networks

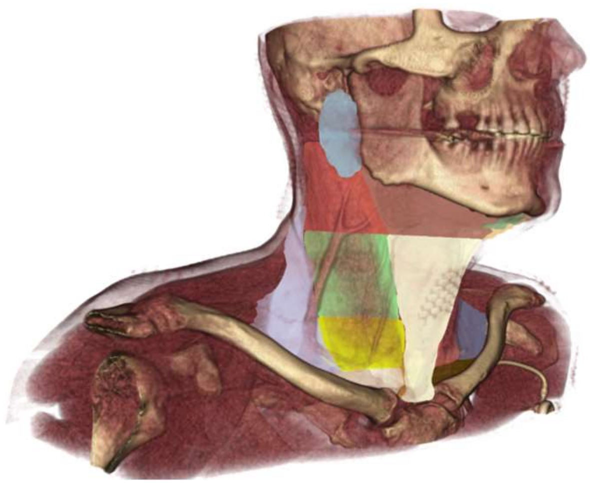
Shao-Lun Lu,[†] Fu-Ren Xiao,[†] Jason Chia-Hsien Cheng, Wen-Chi Yang, Yueh-Hung Cheng, Yu-Cheng Chang, Jhih-Yuan Lin, Chih-Hung Liang, Jen-Tang Lu, Ya-Fang Chen, and Feng-Ming Hsu



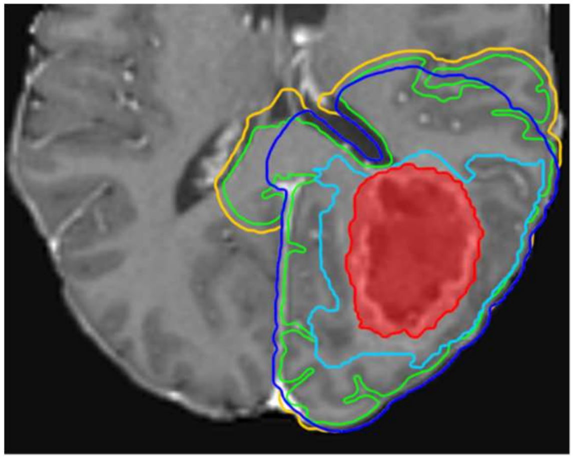
2) CTV (Clinical Target Volume) autodelineation

Automated CTV creation

Anatomically-defined CTVs
e.g., lymph node levels



Rule-based CTVs
e.g., glioma

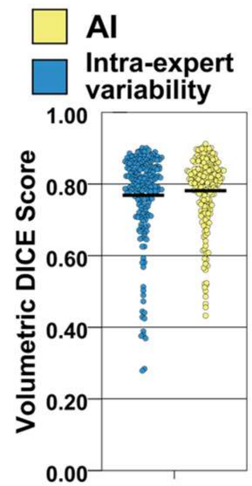


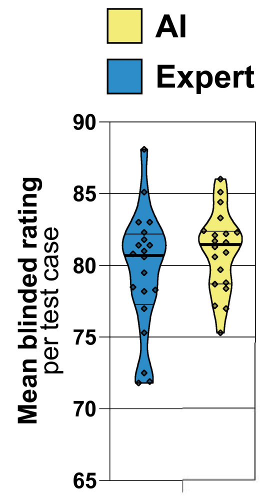
2) CTV auto-delineation: Anatomically-defined CTVs

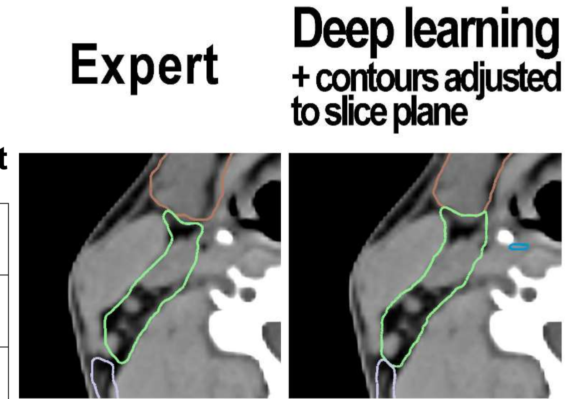
Example: H&N-lymph node target volumes:

- **NnU-net 2d/3d ensemble**
- **Equivalence:**
  AI vs. **expert target volumes** in **blinded evaluation**
- **Accuracy** of **AI target volumes within intra-observer variability**

⇨ **Anatomically-defined CTVs can be automated at human-comparable level using U-Nets.**



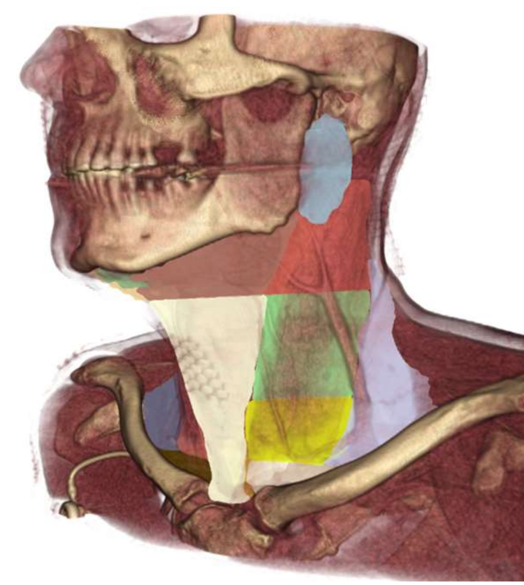




frontiers | Frontiers in Oncology
TYPE Original Research
PUBLISHED 16 February 2023
DOI 10.3389/fonc.2023.1115258

Deep learning for automatic head and neck lymph node level delineation provides expert-level accuracy

Thomas Weissmann[1,2], Yixing Huang[1,2], Stefan Fischer[1,2], Johannes Roesch[1,2], Sina Mansoorian[1,2], Horacio Ayala Gaona[1,2], Antoniu-Oreste Gostian[2,3], Markus Hecht[1,2], Sebastian Lettmaier[1,2], Lisa Deloch[1,2,4], Benjamin Frey[1,2,4], Udo S. Gaipl[1,2,4], Luitpold Valentin Distel[1,2], Andreas Maier[5], Heinrich Iro[2,3], Sabine Semrau[1,2], Christoph Bert[1,2], Rainer Fietkau[1,2] and Florian Putz[1,2*]

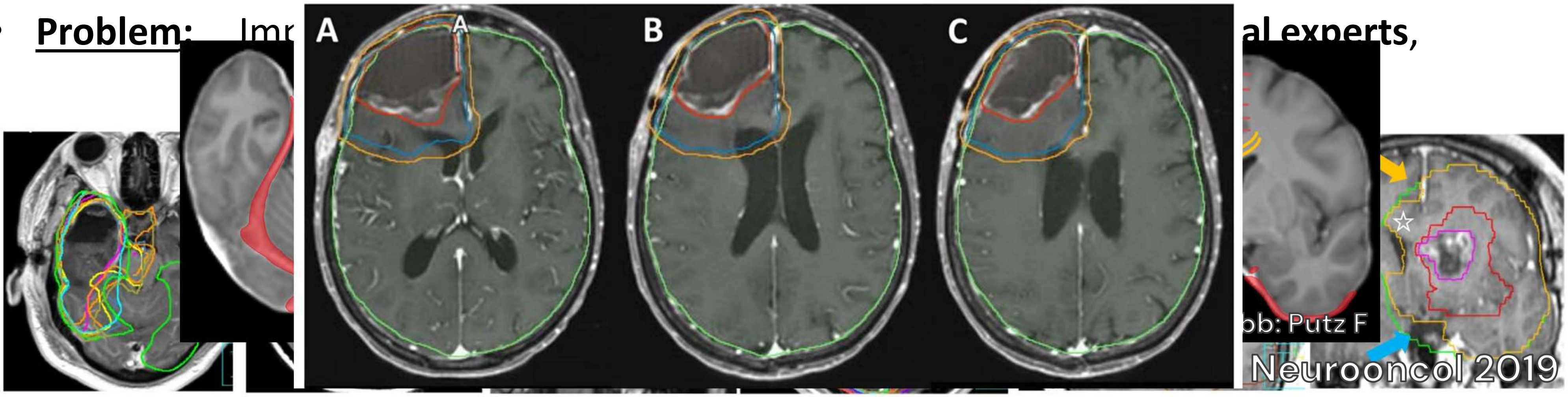


KRUSER T J NEUROONCOL 2019; SHUSHARINA RADIOTHER ONCOL 2020; DANFANG PLOS ONE 2014

2) CTV auto-delineation: Rule-based CTVs

Guideline-based RT target volume definition in gliomas (ESTRO-EANO / RTOG-NRG)

- **Principle:** Tumor expansion (15 – 20 mm) but **considering anatomical barriers**
- **Problem:** Imr … **al experts**,



- **Solution:** **Automated CTV creation with shortest path algorithms**

2) CTV auto-delineation: Rule-based CTVs

Automated CTV creation with "shortest path" algorithms:

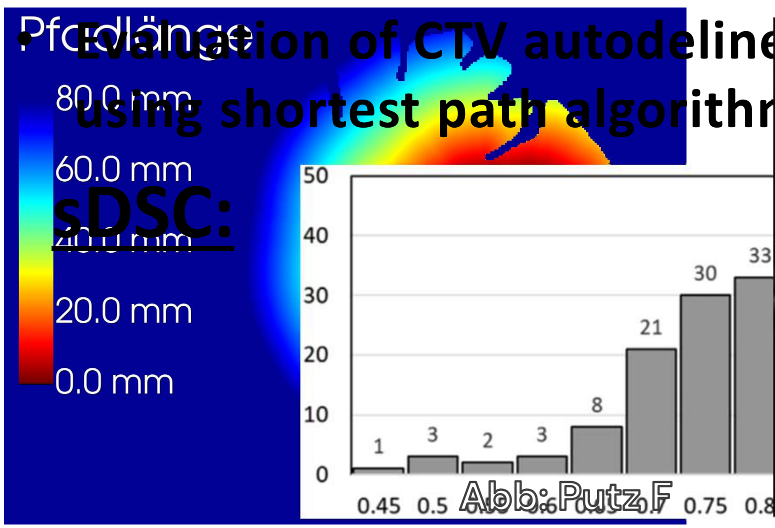
- **Principle:** **Calculation of distance transform (3D Map of shortest path lengths) starting** from **tumor (GTV) surface considering anatomical barriers**
- **Prerequisite:** **Binary map** of **obstacles / barriers**

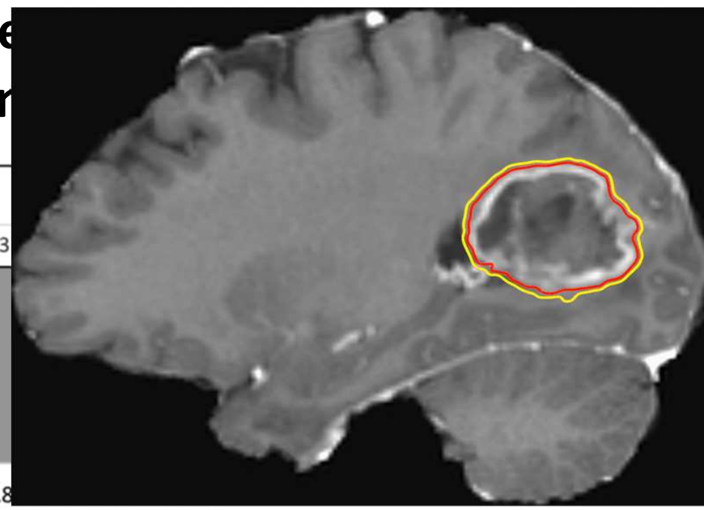
⇨ *Adjustable **CTV margins** through **thresholding specific isodistance surfaces***

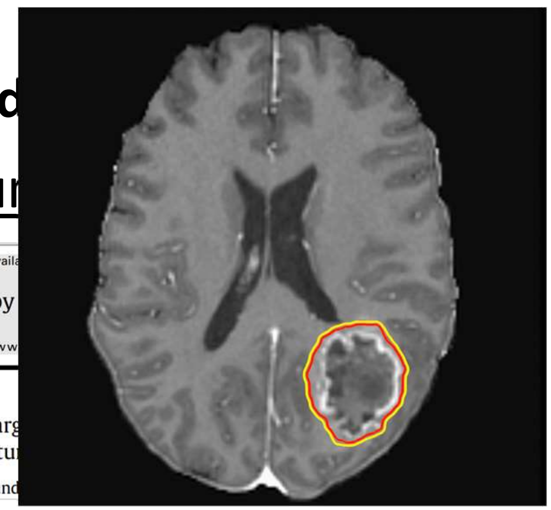
- **Evaluation of CTV autodeline**

using shortest path algorithr

sDSC:



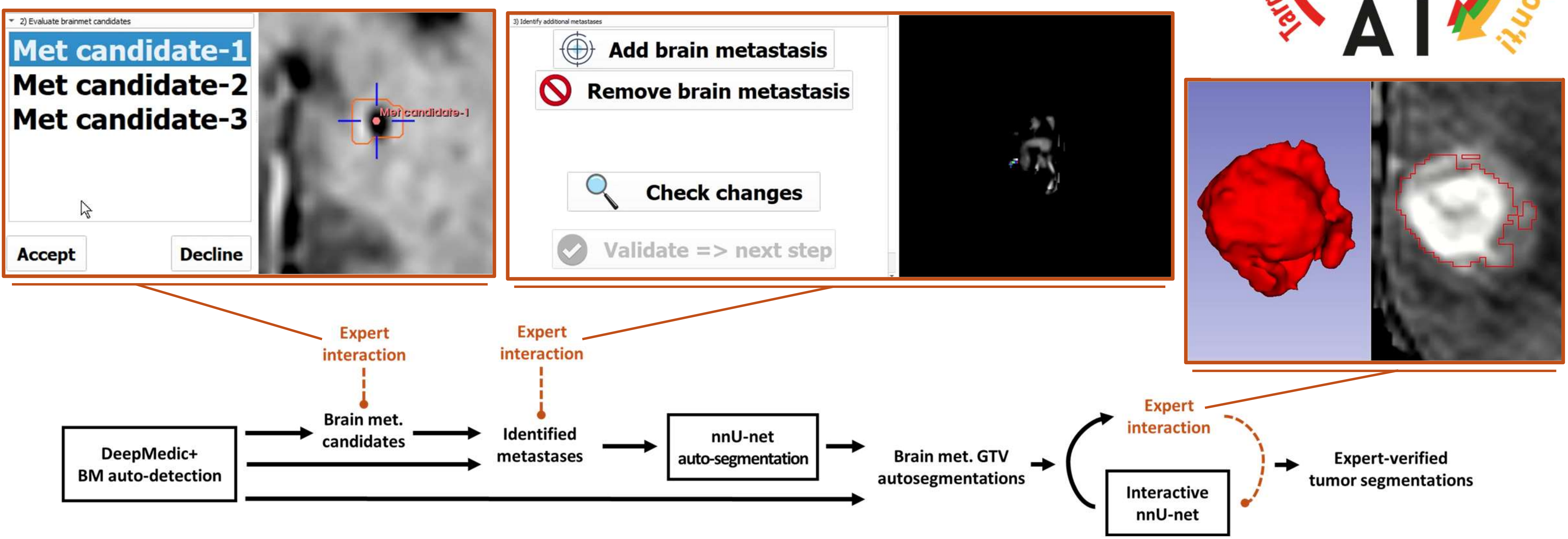




3) Expert-AI Interaction: Interactive Models & Workflows

Integration of human experts into AI workflows:

Example of an interactive AI-assisted workflow for brain metastases:

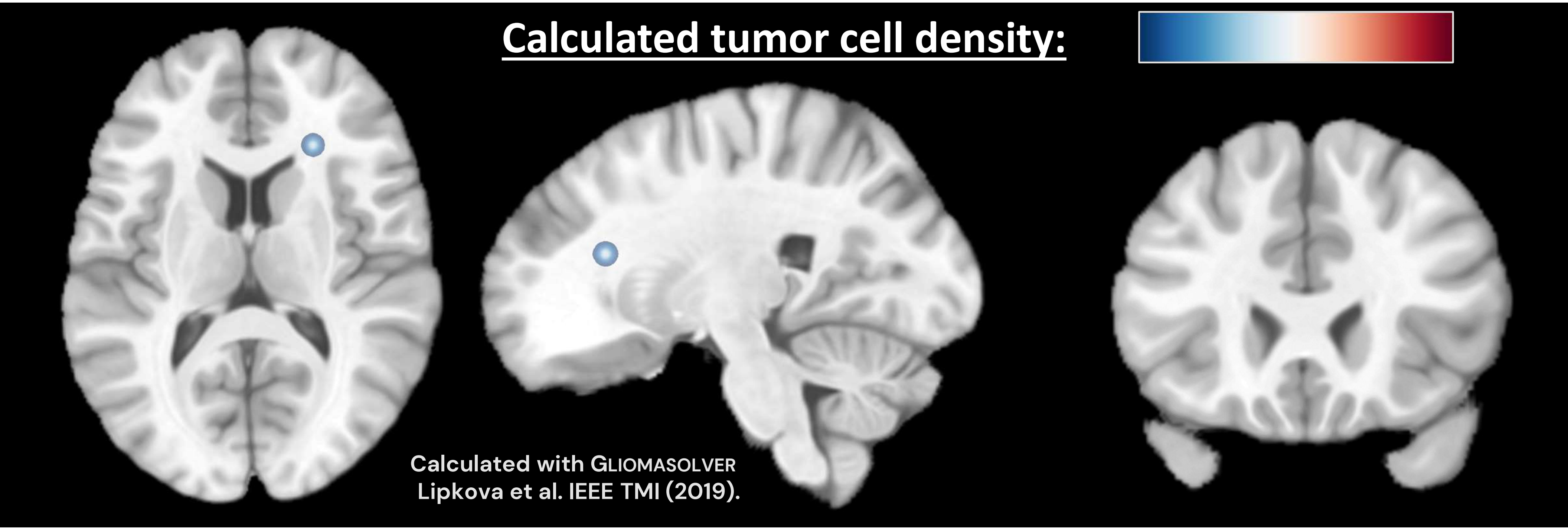


4) Tumor growth & tumor infiltration prediction

1. Prediction of tumor infiltration using reaction-diffusion models:

Challenge: *Inverse problem of model calibration for individual patients?*

$$\frac{\partial \mathbf{u}}{\partial t} = \nabla \cdot (\mathbb{D}\nabla \mathbf{u}) + \rho \mathbf{u}(1 - \mathbf{u})$$

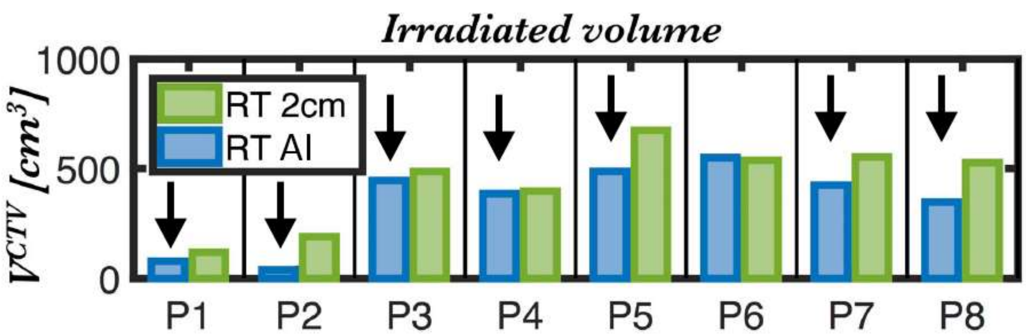


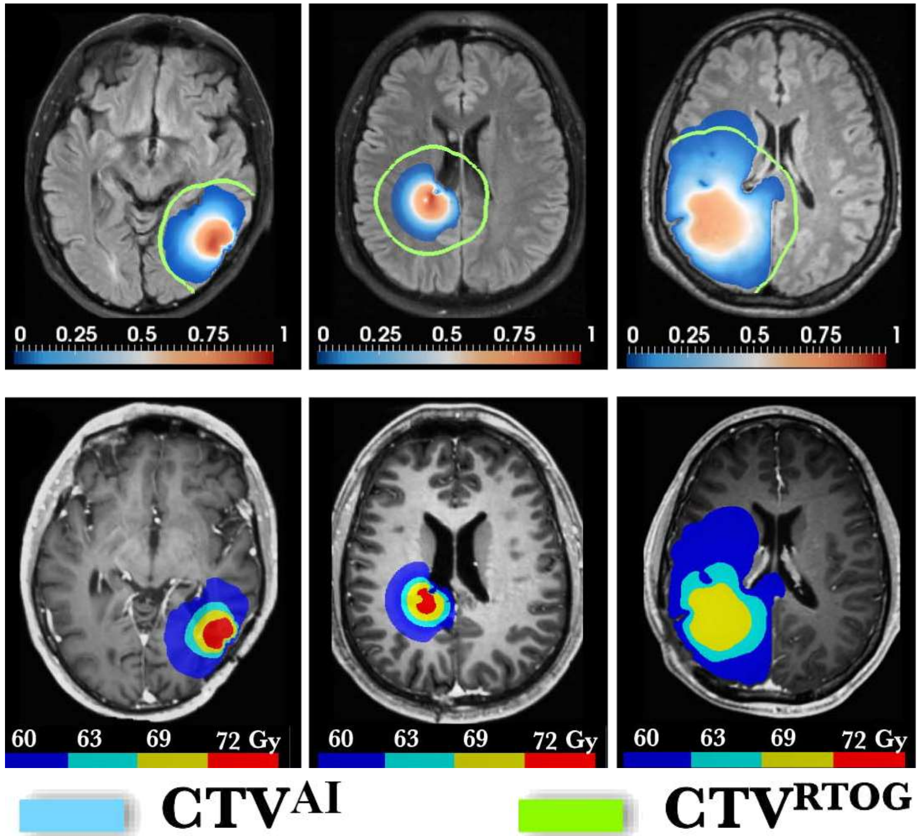
4) Tumor growth & tumor infiltration prediction

1. Prediction of tumor infiltration using reaction-diffusion models:

Lipkova et al. (2019): Early clinical evaluation (retrospectiv, n = 8 patients)

- **Model calibration:** Bayesian modelling
  Alternative: 3D-CNN in atlas space
  (Learn-Morph-Infer)
- **AI-target volumes smaller than RTOG-target volumes while having same coverage of recurrences.**

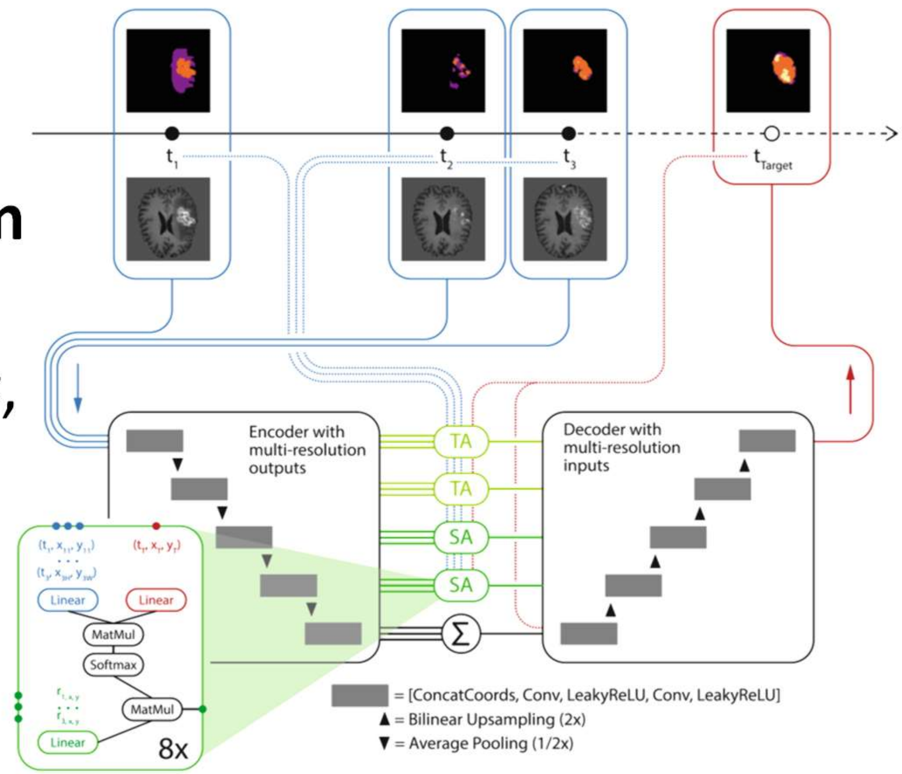




4) Tumor growth & tumor infiltration prediction

2. Tumor growth prediction using deep learning models („data-driven"):
e.g., Continous-Time Deep Glioma Growth (Petersen, MICCAI 2021)

- **Hybrid-CNN Transformer**
  (Neural Process variant)
- **Learns tumor growth prediction from longitudinal training dataset:**
  Variable number + timing of MRI scans, variable prediction into the future



Continuous-Time Deep Glioma Growth Models

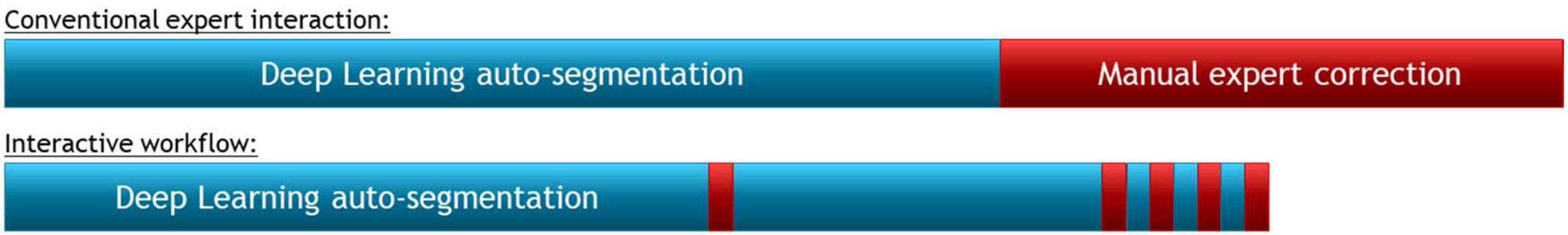
Jens Petersen[1], Fabian Isensee[2], Gregor Köhler[1] Paul F. Jäger[3], David Zimmerer[1], Ulf Neuberger[4], Wolfgang Wick[5,6], Jürgen Debus[7,8,9], Sabine Heiland[4], Martin Bendszus[4], Philipp Vollmuth[4], and Klaus H. Maier-Hein[1]

Summary & Conclusions

- **Deep learning auto-segmentation models** can **improve tumor contouring** as **support systems**.
- **Computer-automated creation** of **standardized clinical target volumes** is also **possible** and **promising.**
- **Since expert validation** and **correction** are **necessary**, the question of **optimal expert-AI interaction becomes important**.
- **Tumor growth modelling** is an interesting **future technology**, but requires **further close-to-the-clinic development** and **evaluation.**

3) Expert-AI Interaction: Interactive Models & Workflows

- **AI auto-segmentation** in **RT planning** requires **expert validation** and **correction**
- **Manual correction time consuming** und **pot. error-prone**



⇨ **Important for the practical use of deep learning models:**

- Design of AI-expert interaction
- **Interactive deep learning models and workflows with the ability for adjustment and correction**