Clinical translation of Prompt-Gamma-Imaging for treatment verification in online-adaptive proton therapy: Overview of achievements and outlook

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Background and aims

Daily Prompt-Gamma-Imaging (PGI) provides benefits for treatment verification (TV) in proton therapy by enabling the detection of anatomical changes during treatment and allowing a potential margin reduction. An additional benefit of PGI-TV emerges in the context of online-adaptive proton therapy (OAPT). There, PGI-TV could not only detect intra-fractional anatomical changes, but also act as a safety net for the adapted treatment within the OAPT feedback loop. Subsequently, we outline translational achievements and next steps towards PGI-TV in OAPT.

Methods

As depicted in Figure 1, (I) we acquired clinical data with a PGI-slit-camera prototype for different tumor locations. For every PGI-monitored fraction, in-room control CT (cCT) with dual-energy scans in treatment position were available. Subsets of these data have already been used to retrospectively evaluate (II-A) the capability of PGI to detect anatomical changes and (II-B) the potential of PGI-TV to reduce range uncertainty margins. (III) Furthermore, we are developing a fully automated online PGI evaluation. For OAPT, this requires processing cone-beam CT (CBCT) scans as input for calculating the PGI reference, which is tested in a first simulation study using different phantom and patient datasets. (IV) Finally, we are preparing an interventional PGI trial for prostate-cancer proton therapy.

Results

According to Figure 2, (II-A) PGI classification models for detecting anatomical changes showed an accuracy of 77% for measured PGI data (prostate) and 93% for realistic PGI simulations (H&N). (II-B) With PGI-TV, combined with DirectSPR-based range prediction, the range uncertainty margin can be reduced from 7mm to 3mm in prostate-cancer treatments. (III) We have reduced the PGI processing time by ~64% and demonstrated in phantoms that the PGI reference simulation can be calculated from CBCTs without relevant limitations. (IV) In our funding-approved interventional trial with daily PGI monitoring and reduced range uncertainty (cf.III), PGI will trigger cCT (with an intended false-positive trigger rate <20%) directly after treatment with adaptions applied on the next treatment day.

Conclusions

Clear progress towards an interventional application of PGI-TV has been made. Its application in OAPT workflows seems particularly beneficial and promising. The first prospective application within an interventional trial is in preparation.

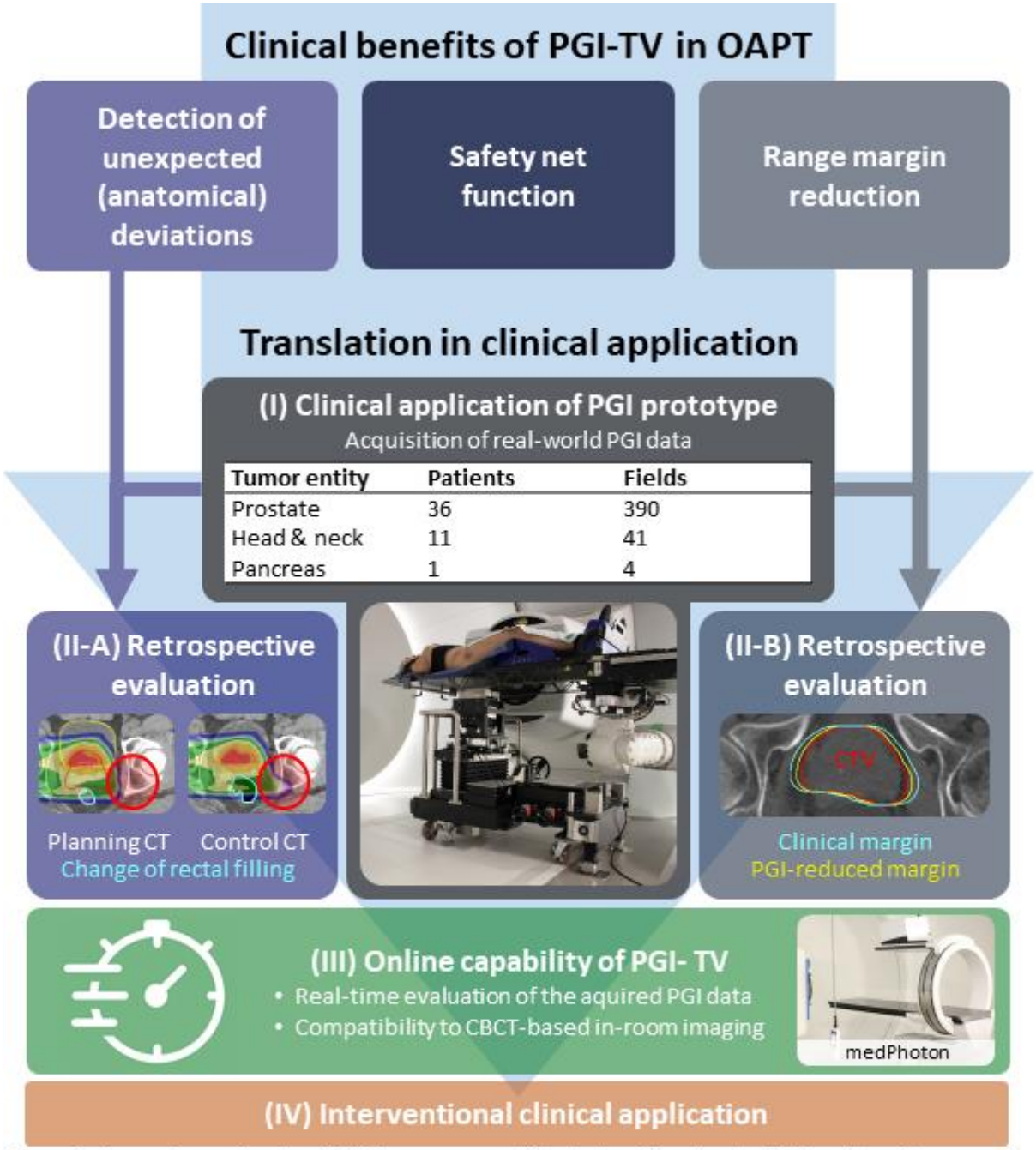

Figure 1: Prompt-Gamma-Imaging (PGI) for treatment verification in online-adaptive PT: Benefits and use-cases & Step-wise clinical translation. (Top) Threefold role of treatment verification with PGI (PGI-TV) for online-adaptive proton therapy (OAPT). **(Bottom)** Outline of step-wise translation of PGI-TV into clinical application: (I) Acquisition of clinical PGI data for various tumor entities which is currently ongoing at our institute. (II) These real-world PGI data are then used for a retrospective evaluation of the abovementioned clinical use cases. (III) For enabling an online evaluation of the PGI data, speed-up of the workflow is necessary. Furthermore, the compatibility of PGI with widespread CBCT in-room imaging, which will be used for treatment plan adaptation in the future, needs to be investigated. (IV) A prospective clinical trial that will not only validate the retrospective evaluations but will also bring the benefits of PGI-TV directly to patients for the first time since its proposal two decades ago.

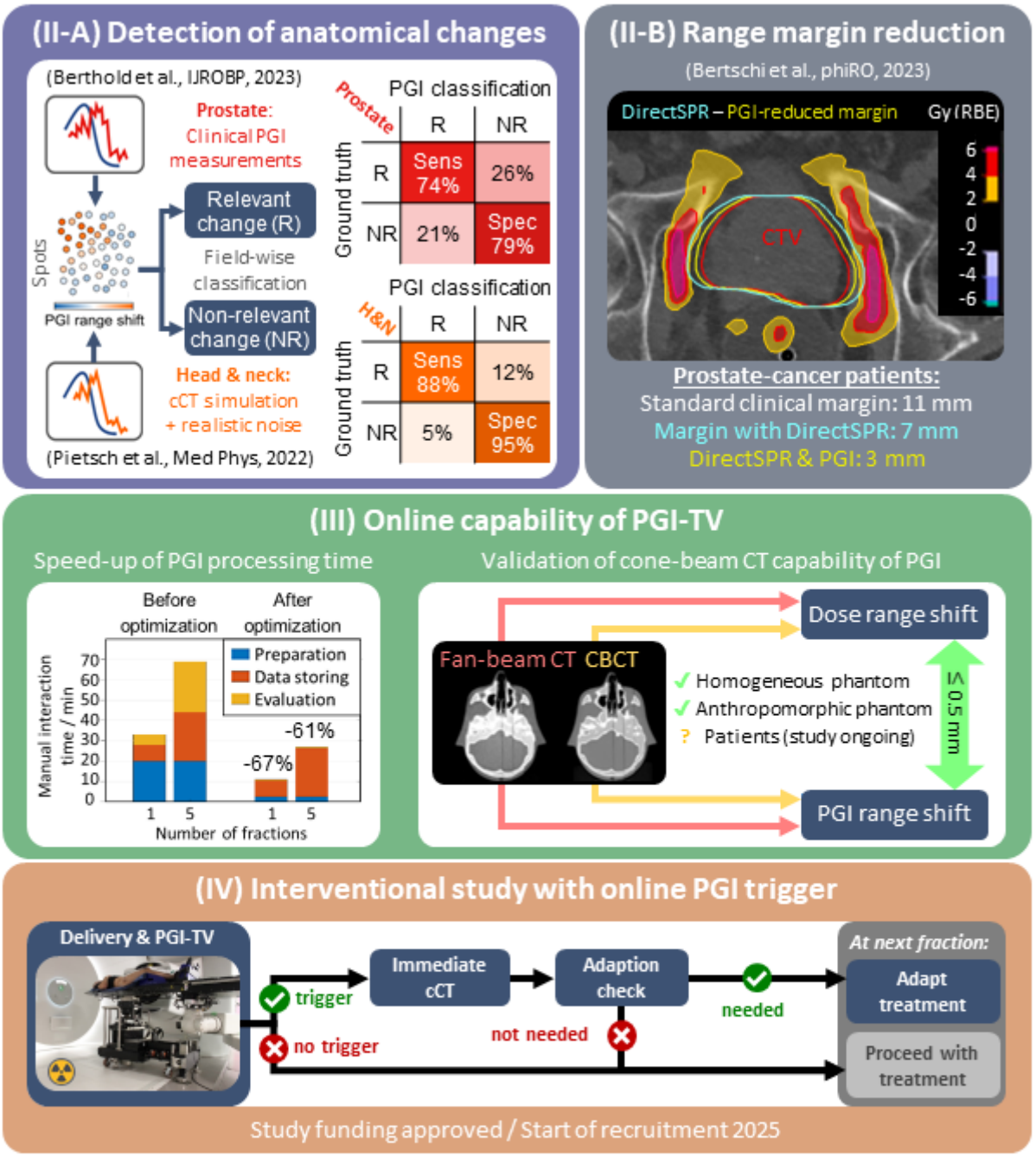

Figure 2: Translational achievements with a second-generation PGI prototype system. (II-A) Quantification of the detectability of anatomical changes using a field-wise classification. Measured PGI data were used for prostate, while results presented for head & neck are based on realistic simulations including realistic PGI system positioning uncertainties and measurement noise. **(II-B)** Quantification of the range margin reduction potential for DirectSPR-based range prediction combined with PGI treatment verification (PGI-TV) in prostate-cancer irradiations. **(III)** Summary of ongoing research to enable the online capability of PGI-TV for OAPT. *Left*: First enhancements of the PGI-TV workflow by increased automation of the processing workflow. *Right*: Concept of validating the cone-beam CT (CBCT) capability of PGI compared to fan-beam CT (FBCT) imaging. **(IV)** Design of the first interventional PGI study for prostate patients with simultaneous range margin reduction.