Introduction

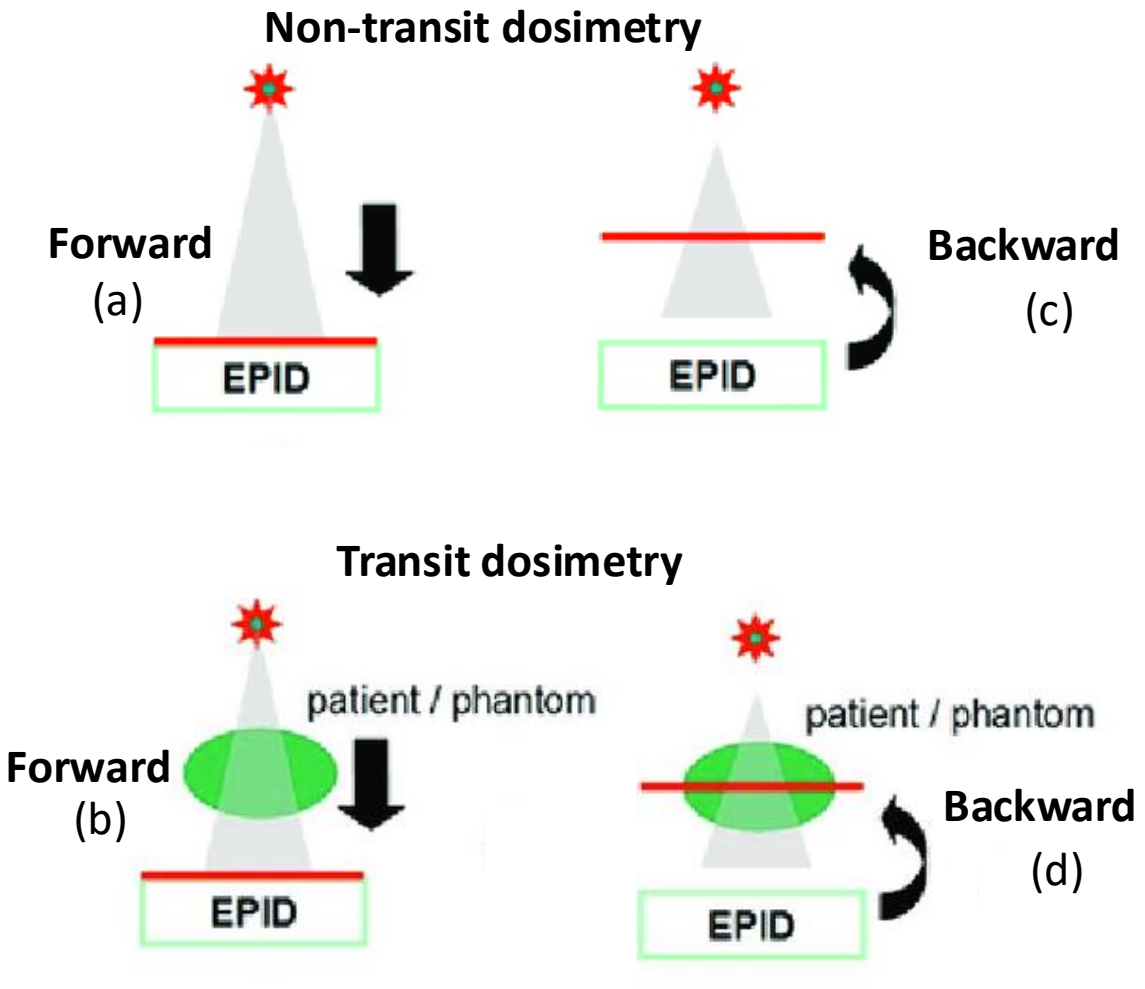
Quick reminder of ARTEMIS project

Background

Van Elmpt W, et al, A literature review of electronic portal imaging forradiotherapy dosimetry. Radiother Oncol. 2008;88:289-309

- Dosimetry: fundamental tool in radiotherapy, that ensures the delivery of radiation to patients to be
  - Safe
  - Accurate
- Among the various dosimetry approaches is EPID: a 2D dose measurement
- EPID dosimetry approaches: non-transit and transit dosimetry
- Transit is *in-vivo* if the "object" is a real patient
- Transit dosimetry is clinically more valuable. Classification into:
  - Methods that verify delivered dose **at patient level** (requiring some reconstruction model)
    - 1D
    - 2D
    - 3D → INTREPID/ARTEMIS ultimate goal: AI
  - Methods that verify dose at EPID level **behind the patient**
    - 2D→ INTREPID/ARTEMIS first step

AAPM Task Group Report 307: Use of EPIDs for Patient-Specific IMRT and VMAT QA



B Mijnheer , IOP Conf. Series: Journal of Physics: Conf. Series 847 (2017) 012024,

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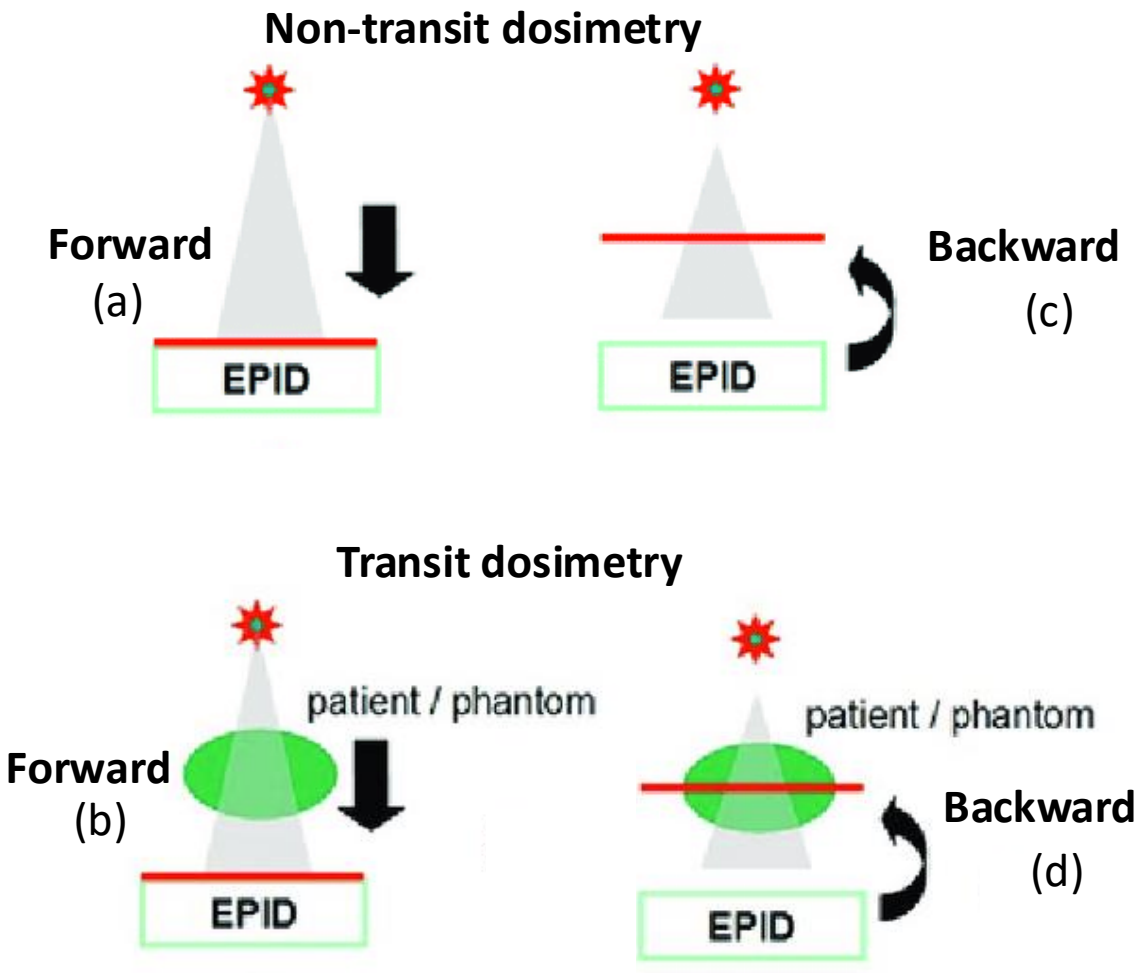
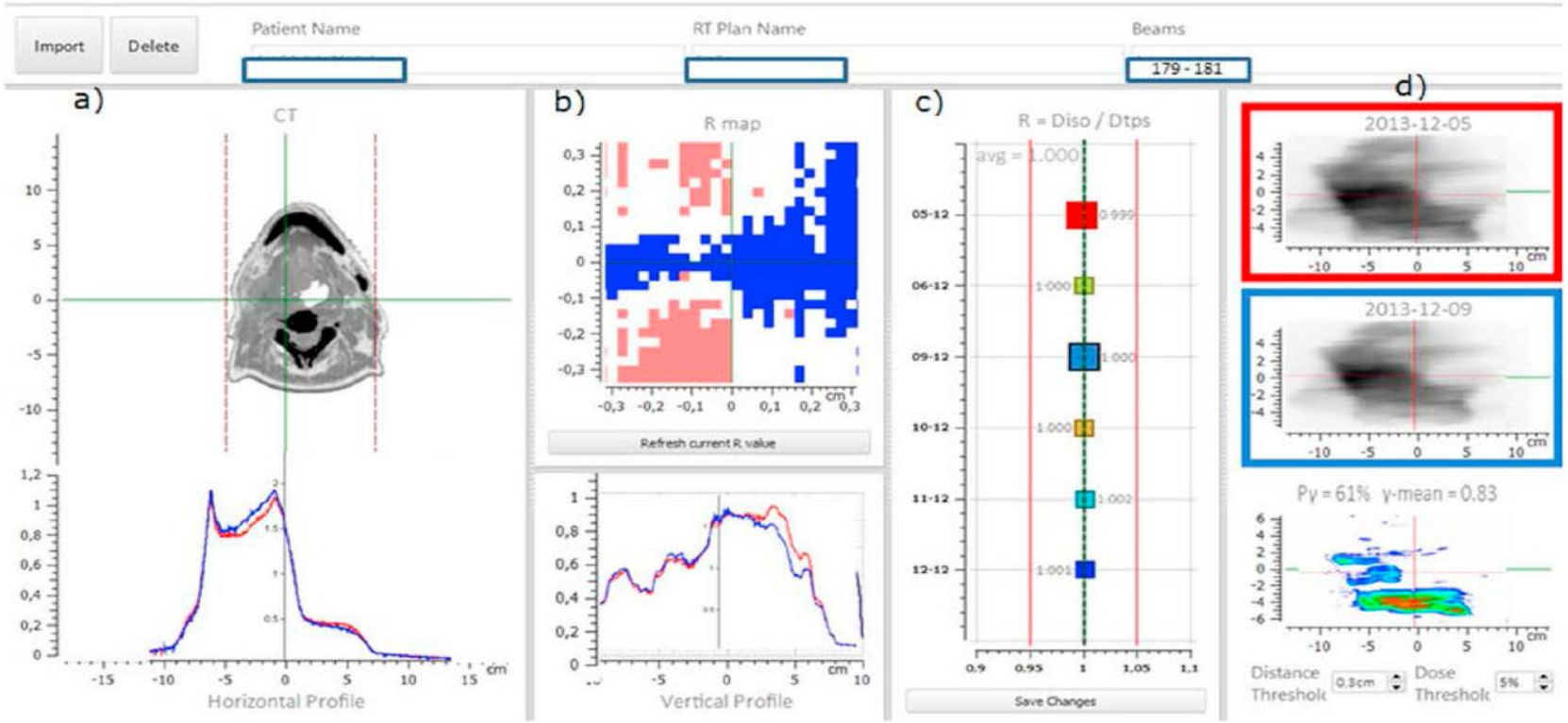
Carlotta



Background

- These transit dosimetry methods are useful, because they can be used to raise alarms during or after patient irradiation (in-vivo) → ALERT system

Commercial alert system, approach= transit, forward



EPID comparison

Software: SOFTDISO (Best NOMOS, Pittsburgh, PA), for in vivo dosimetry

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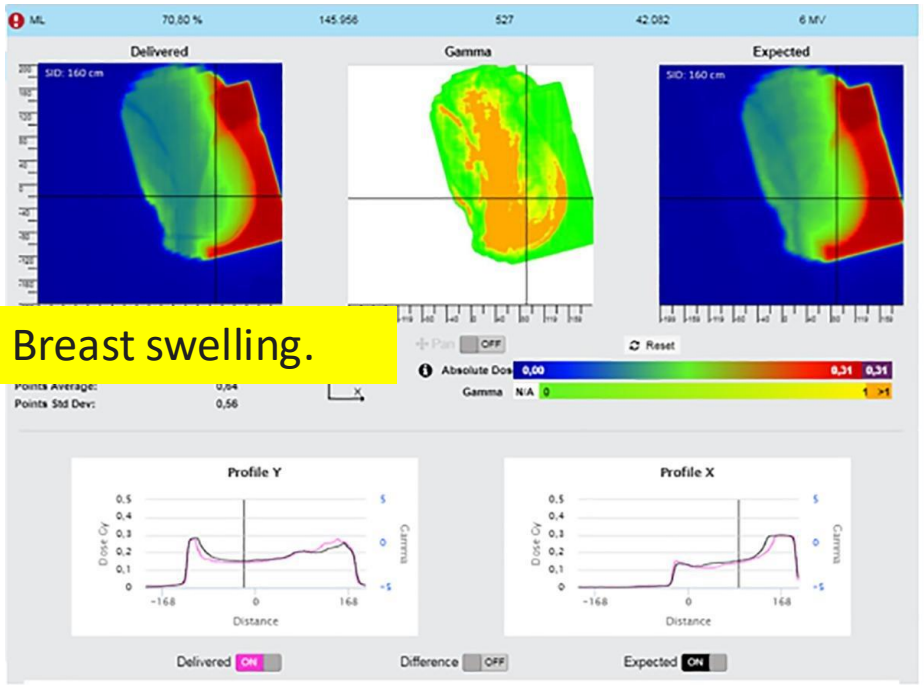
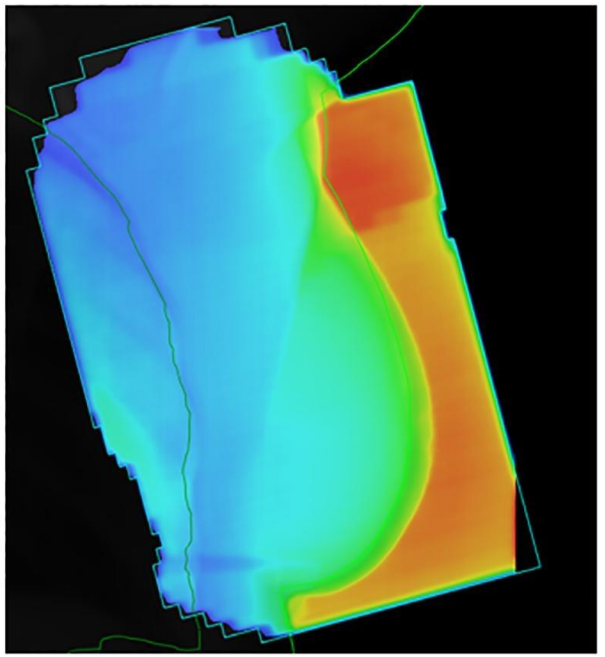
Commercial alert system, approach: transit, backward (*in-vivo*)



Breast swelling.



Measured dose in **patient** and comparison with TPS

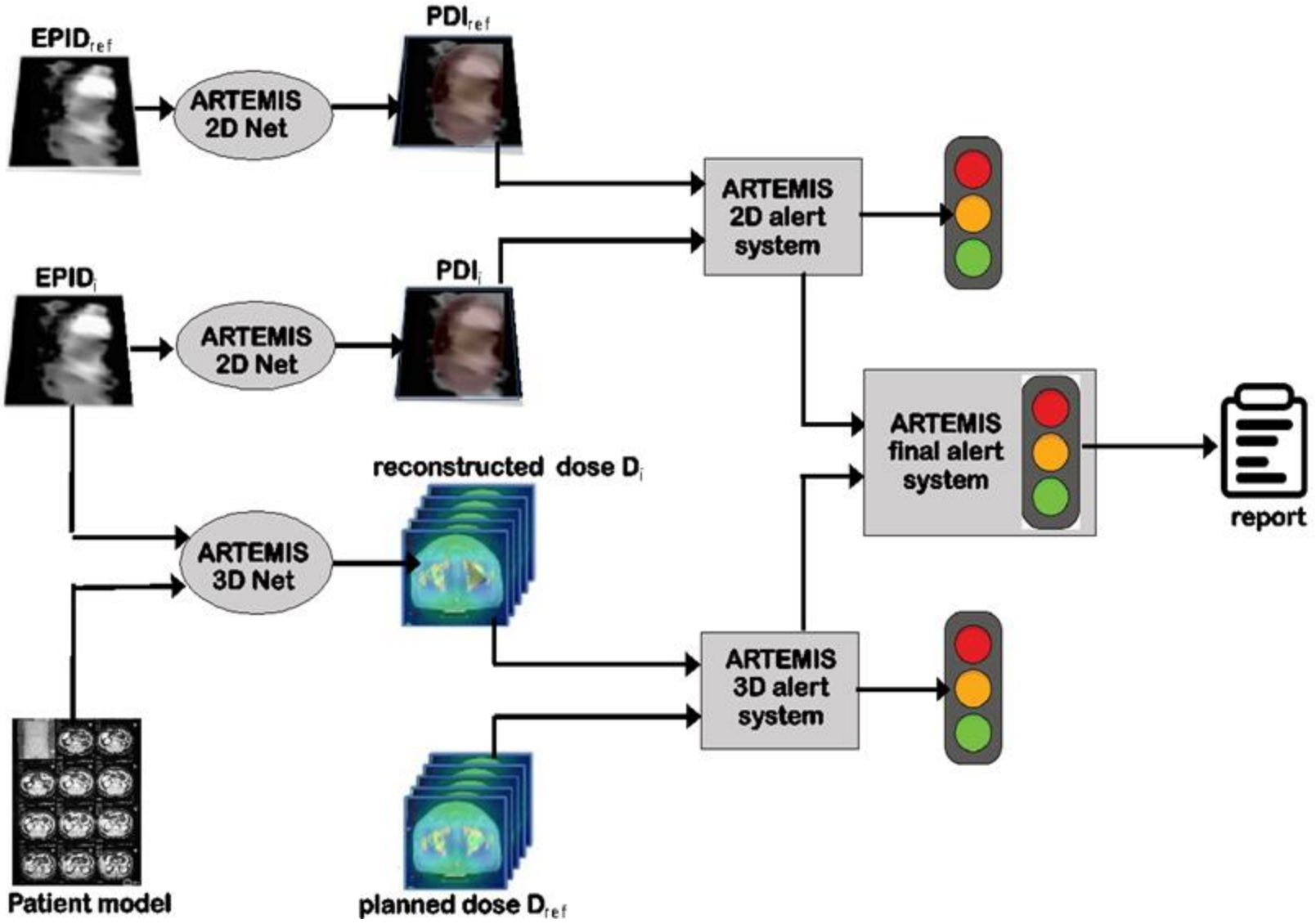
Software: PerFRACTION system (Sun Nuclear. Melbourne, FL) for in vivo dosimetry

Bossuyt, Evy et al., Evaluation of automated pre-treatment and transit in-vivo dosimetry in radiotherapy using empirically determined parameters Physics and Imaging in Radiation Oncology, Volume 16, 113 – 129, 2020

Background

- ARTEMIS: 2D, 3D and combined alert system
- 2D AI model for converting EPID to PD is ”ready” and documentation is in progress
- Can start with 2D alert system

Rossana Emmanuel



2D DL-based alert system

Several steps in development:

- Data acquisition with intentionally introduced errors
- Define metrics to use in 2D alert system
- Define and decide comparison analysis strategy to be used
- Test the system on situations closer to real patients

2D DL-based alert system

Several steps in development:

Data acquisition with intentionally introduced errors

Status:

- ✓ EPID Data taken in december and march at Carreggi
  - ✓ Predicted PD from TPS available

Future:

- More data with new phantom(s)

Phantom	MUs	Setup	Angle	Anatomy
SLAB phantom				5×5 2×2
CIRS	10×10 1×15	10×10 1×15	5×5	
Multi-Plug	5×5	5×5	5×5	

Summary data acquired in March 2025 (red were acquisitions that had some difficulties in data analysis)

2D DL-based alert system

Several steps in development:

Define metrics to use in 2D alert system

Status:

- ✓ About 30 papers read about 2D EPID alert systems
- ✓ Preliminary selection made of quantities
- ✓ Implemented in analysis

N. Dogan et al., AAPM Task Group Report 307: Use of EPIDs forPatient-Specific IMRT and VMAT QA Med Phys. 2023;50:e865–e903.

A.H. Zhuang and A.J.Olch, Sensitivity study of an automated system for daily patient QA using EPID exit dose images, J.Appl. Clin.Med.Phys. 2018, 19-3:114-124

S.Both et al, A study to establish reasonable action limits for patient-specific quality assurance in IMRT, J. Appl. Clin.Med.Phys. 2007,vol8, nr 2, p1

S. Celi, EPID based in-vivo dosimetry system: clinical experience and results, J. Appl. Clin.Med.Phys. Vol 17, nr 3, 2016 (EPIgray)

R. Howel et al, Establishing action levels for EPID QA for IMRT, J. Appl. Clin.Med.Phys. Vol 9, nr 3, 2008

T. Fuangrod, et al, Investigation of a real time EPID-based patient dose monitoring system using site specific control limits, Rad. Onc. (2016) 11:106

S.R.Avelino et al., Evaluation of an EPID in-vivo monitoring system using local and external independent audit measurements, J.Appl. Clin.Med.Phys 2022;23;e13822

A.F.I. Osman and N.M Maalej, Applications of machine and deep learning to patient-specific IMRT/VMAT quality assurance, , J.Appl. Clin.Med.Phys 2021; 22(0); 20-36

Good news: not much about AI!

2D DL-based alert system

Several steps in development:

Define metrics to use in 2D alert system

- Portal dose distributions of expected and measured
- 2D dose difference distribution
- Horizontal and vertical dose profiles in center
- Mean normalized difference (normalized to max of ref)

$$\Delta D_{norm} = 100\% \times \frac{1}{N_{v \in T}} \sum_{v \in T} \frac{|D_e - D_r|}{D_r^{max}}$$

- Mean difference (no normalization and no absolute value)

$$\Delta D = 100\% \times \frac{1}{N_{v \in T}} \sum_{v \in T} (D_e - D_r)$$

Status:

- ✓ About 30 papers read about 2D EPID alert systems
- ✓ Preliminary selection made of quantities
- ✓ Implemented in analysis

- Gamma index 2D-distribution
- Passing rate:

$$PR = \frac{\sum_{v,pass} \Gamma_v^{pass}}{\sum_{v,tot} \Gamma_v^{valid}}$$

- Mean gamma-index value (?)

2D DL-based alert system

Several steps in development:

Define metrics to use in 2D alert system

- Portal dose distributions of expected and measured
- 2D dose difference distribution
- Horizontal and vertical dose profiles in center
- Mean normalized difference (normalized to max of ref)

$$\Delta D_{norm} = 100\% \times \frac{1}{N_{v \in T}} \sum_{v \in T} \frac{|D_e - D_r|}{D_r^{max}}$$

AAPM TG307

PD vs PD_{ref}: ±5%
PD vs PD_{TPS} : ±10%

- Mean difference (no normalization and no absolute value)

$$\Delta D = 100\% \times \frac{1}{N_{v \in T}} \sum_{v \in T} (D_e - D_r)$$

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Not much info, 5 cGy quoted in some papers

- Gamma index 2D-distribution
- Passing rate:

$$PR = \frac{\sum_{v,pass} \Gamma_v^{pass}}{\sum_{v,tot} \Gamma_v^{valid}}$$

AAPM TG307

- Frequently quoted in 2D: 3mm/3%: GPR>0.9 or 0.95
- Tolerance and parameters depend on technique and site
- Parameters not always quoted
- PD vs PD_{TPS} --> relax criteria (for example, 5 mm/3%)

Status:

- ✓ About 30 papers read about 2D EPID alert systems
- ✓ Preliminary selection made of quantities
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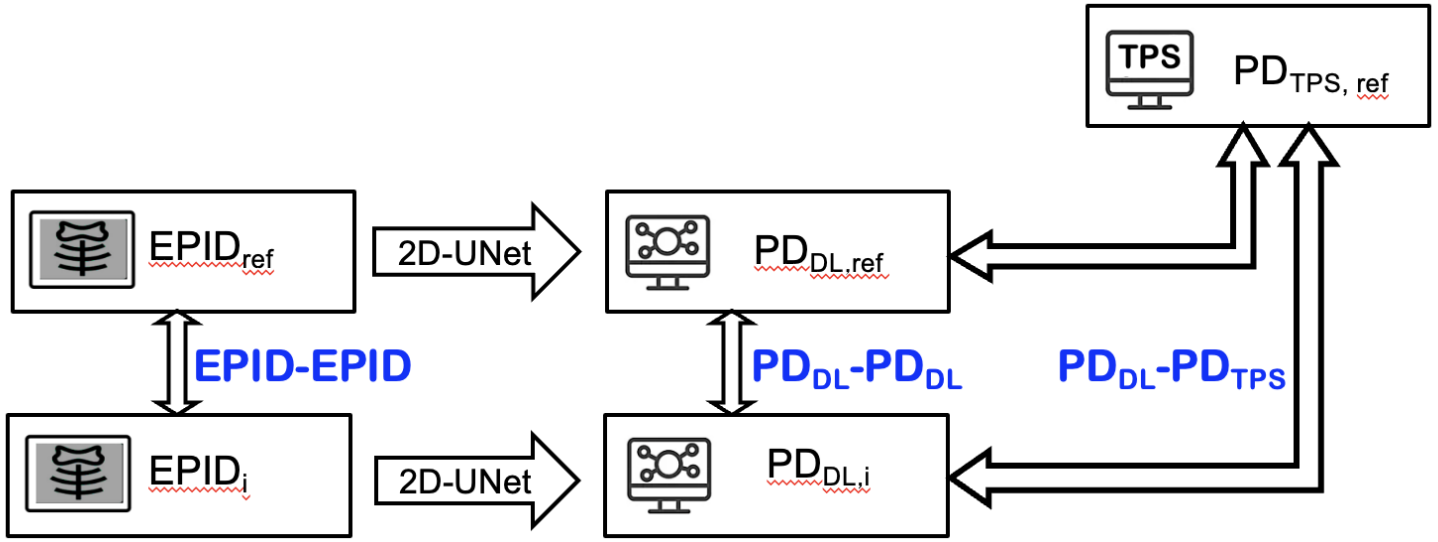
2D DL-based alert system

Several steps in development:



Define and decide comparison analysis strategy to be used

- Strategy **PD_{DL}-PD_{TPS}**: PD from TPS is reference ($PD_{TPS, ref}$), to be compared with PD_i from DL model $PD_{DL,i}$ → preferred method
- Strategy **PD_{DL}-PD_{DL}**: $PD_{DL, ref}$ (e.g first day) vs PD_i (day N)
- Strategy **EPID-EPID**: $EPID_{ref}$ (e.g first day) vs $EPID_i$ (day N): simple

Status:

✓ Applied three for some of the data acquired

✓ Investigated how the DL model influences the action level for the phantoms

2D DL-based alert system

Several steps in development:

Test the system on situations closer to real patients

Status:

- ✓ Develop 3D printed phantoms (design+material)
- Acquire data with errors and analyze them → unknown for AI model!
- Use new phantoms for training and validation of AI model?

2D DL-based alert system

Several steps in development:

Data acquisition with intentionally introduced errors	Carlotta + tutti
Define metrics to use in 2D alert system	Aafke, Cinzia
Define and decide comparison analysis strategy to be used	Rossana, Emmanuel
Test the system on situations closer to real patients	Rossana, Aafke, Stefania

Program today

- Presentation by Emmanuel (some overlap with Rossana, to come independently to the same results)
  - Data March 28, strategy B and C (PD versus PD_no errors, and PD versus PD_TPS) for all phantoms
  - Error sources tested for all phantoms
    - MU
    - Setup
    - Material added
    - Angle
  - Tests with varying gamma-parameters for several phantoms

- Presentation by Rossana
  - Data March 28, all analyzed, focus on the cases where PD_TPS corresponded ok with PD measured
  - Error sources tested
    - MU
    - Setup
    - Material added
    - (Angle tested but not included)
  - Strategy BLB tested → feedback appreciated!
- Discrepancies identified between December and March data

- Presentation by Lorenzo: development of 3D AI model

- Presentation by Rossana
  - Design and material choice of 3D printed phantom

- Presentation by Carlotta:
  - Data acquisition

Program today

ARTEMIS and INTREPID joint meeting

Friday 9 May 2025, 12:00 → 16:05 Europe/Rome

Careggi Hospital, Florence

12:00 → 12:20	**Introduction** **Speakers**: Aafke Christine Kraan (Istituto Nazionale di Fisica Nucleare), Cinzia Talamonti (Istituto Nazionale di Fisica Nucleare)	20m
12:20 → 13:00	**Data analysis for AI-based 2D EPID alert system** **Speaker**: Rossana Lanzillotta (University and INFN, Pisa)	40m
13:00 → 13:25	**Development of 3D-printed phantom for AI-based dose verification in radiotherapy** **Speaker**: Rossana Lanzillotta (University and INFN, Pisa)	25m
13:25 → 14:30	**Lunch**	1h 5m
14:30 → 14:55	**Data analysis of measurements acquired on March 28** **Speaker**: Emmanuel Uwitonze (INFN Pisa)	25m
14:55 → 15:20	**Development of 3D AI-model for in-vivo dose verification** **Speaker**: Dr Lorenzo Marini (Istituto Nazionale di Fisica Nucleare)	25m
15:20 → 15:45	**New data acquisitions** **Speaker**: Carlotta Mozzi (University of Firenze)	25m
15:45 → 16:00	**Discussion and plans** **Speaker**: All participants	15m

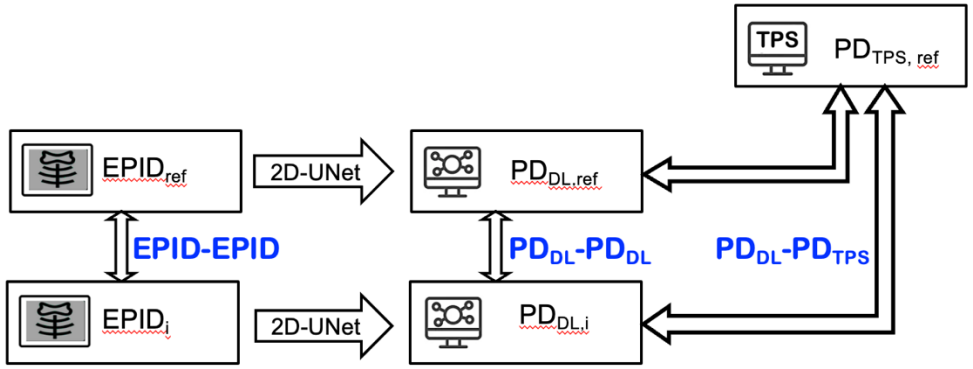
Summary of comparison RL PD_{DL}-PD_{DL}

- Added material:
  - 10 x 10 cm^2 field on solid water:
    - Check
  - 2 x 2 cm^2 field on solid water: from interpolation, it seems like
    - 3.0 mm is detectable (3%/3mm)
    - 2.5 mm is detectable (2%/2mm)
    - 1.7 mm is detectable (1%/1mm)

- Position:
  - 5 x 5 cm^2 field on MultiPlug:
    - 4.0 mm is detectable (3%/3mm)
    - 2.6 mm is detectable (2%/2mm)
    - 1.0 mm is detectable (1%/1mm)
  - 1 x 15 cm^2 field on CIRS:
    - Nothing is detectable, even with smallest limits

- MUs
  - 5 x 5 cm^2 field on Multi Plug:
    - ~103 MU can be detected (3%/3mm) (interpolated)
    - ~102 MU can be detected (2%/2mm) (interpolated)
    - ~101 MU can be detected (1%/1mm) (interpolated)
  - 1 x 15 cm^2 field on CIRS: from interpolation, it seems like
    - 109 MU is detectable (3%/3mm)
    - 105 MU is detectable (2%/2mm)
    - 102 MU is detectable (1%/1mm)

Discussion points



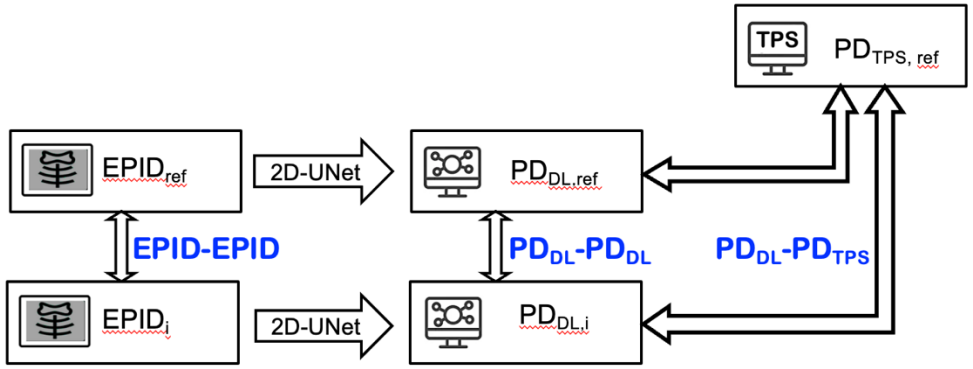
- EPID-EPID:
  - ok: very similar values as PD_{DL}-PD_{DL}
  - compare (almost) raw data so direct method → include it in 2D alert system.

- PD_{DL}-PD_{DL}: ok, gives similar results but advantage is that we have dose values, so can use also ΔD (dose values in Gy)

- PD_{DL} vs PD_{TPS}: most valuable (independent, not data dependent), but the ground truth measurement is sometimes off.
  - Is it normal?
  - Loosen the tolerance criteria? Ok for comparing TPS with situation without errors ($PD_{DL,ref}$-PD_{TPS}), but increasing tolerances means that also the introduced errors would not be detected… so no.
  - Raise the TH and use local gamma? Helps a bit (Emmanuel) but not sufficient
  - Compare the $PD_{DL,ref}$-PD_{TPS} with less strict criteria (5%/3 mm?) → if passes, use for the rest of the measurements the PD without errors ?

- Some cases very problematic, for example 1x 15 cm^2 field on CIRS was problematic: shifts not detected even with 1mm/1% tolerance (with 10% TH and global analysis). Investigate raising the gamma-index threshold and using local gamma, but probably the material is homogeneous. Field is extremely narrow (point shape)

Discussion points



- Opinion about what to quote as 'standard' strategy in thesis for Rossana or presentation… PD_{DL}-PD_{DL} or PD_{DL} vs PD_{TPS}?
  - With TPS most interesting
    - But some phantoms cannot really be included if they start far from 100%
  - But the plots that are easiest to present are without TPS (they all start from 100% and are all regular and behave logically).
  - EPID-EPID: could be used as cross check to verify that the output of the alert by the DL model is reasonable.