Practical method for CBCT protocol optimization

Núria Jornet

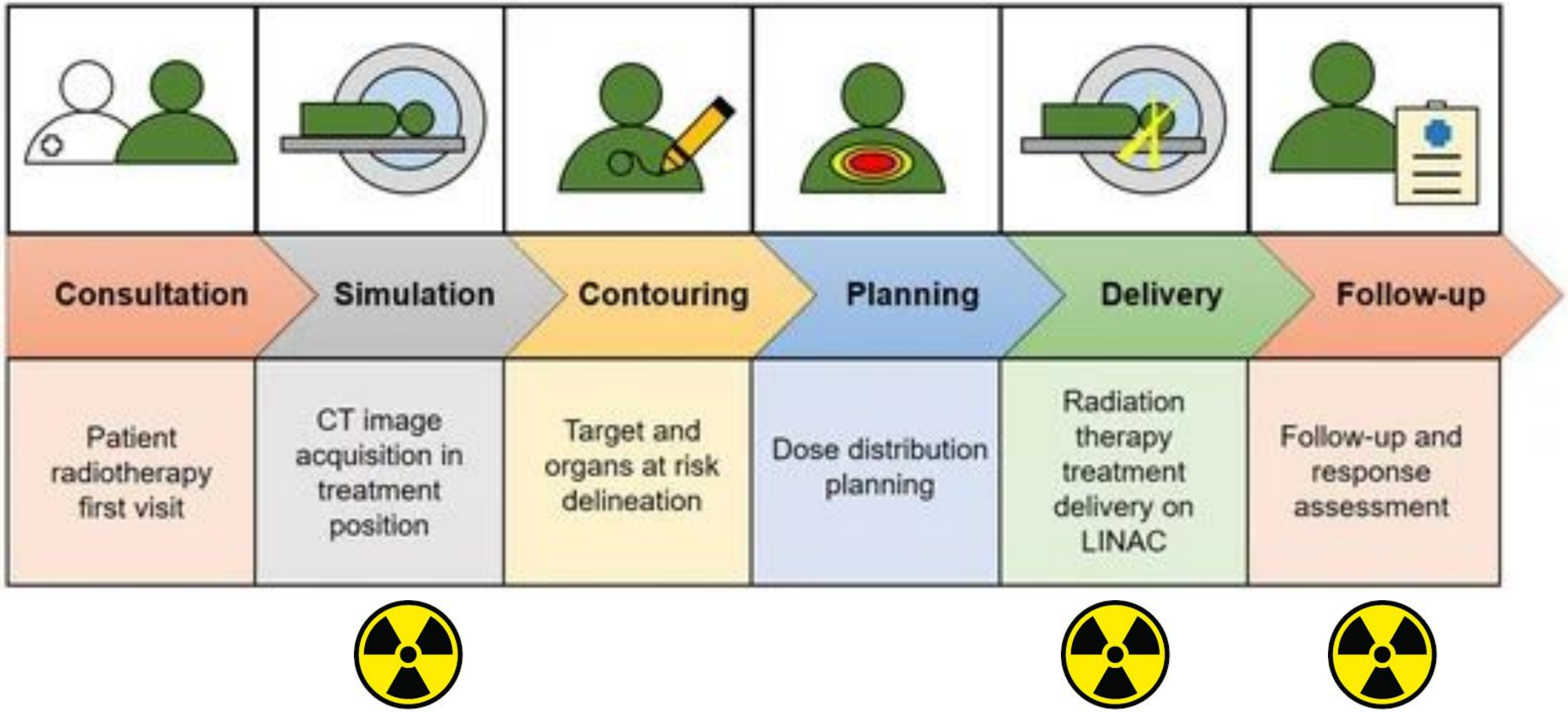
Servei de Radiofísica i Radioprotecció

Hospital de la Santa Creu i Sant Pau

Barcelona

HOSPITAL DE LA SANTA CREU I SANT PAU
UNIVERSITAT AUTÒNOMA DE BARCELONA

Radiotherapy process- use of kV imaging



G. Marvaso et al. Appl. Sci. 2022

Use of kV imaging-recap

Imaging for treatment planning

Volume delineation (CT, MRI, PET-CT)

Patient model for radiation transport and absorbed dose calculation (CT)

Imaging for treatment verification

Patient positioning (2D kV or MV; CBCT, surface imaging)

Monitor changes in body contour/internal structures/tumour (CBCT, US, MRI)

Patient model for re-planning (CBCT/CT)

Use of kV imaging-dose quantities and optimisation

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CT (DLP and CTDI)

Dose reduction strategies
DRL (diagnostic)

CBCT (DLP ,CTDI , $K_{a,r}$, P_{KA})

- Dose optimization seldomly done
- Lack on information of the dose delivered due to kV imaging

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Use of kV imaging-dose quantities and optimisation

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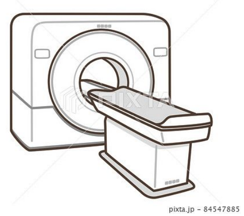

CT (DLP and CTDI)

Dose reduction strategies
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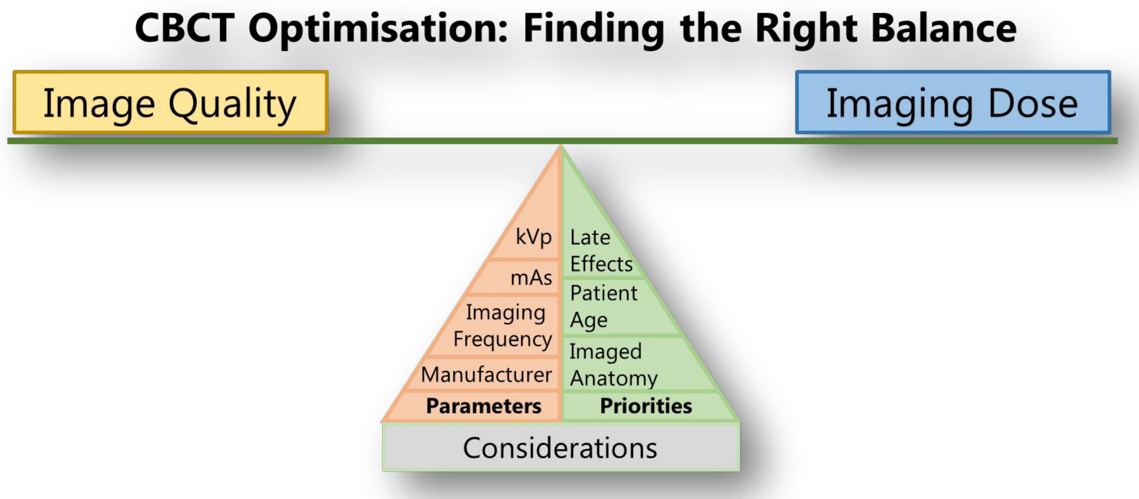
Justification and optimisation of IGRT

Justification:
Detection of potential set up errors
Achieving the required geometric accuracy
Clearly visualising the anatomical region for matching
Aplying adaptive strategies

Optimisation:
The dose has to be kept as low as reasonably possible



IPEM audits of imaging dose to patients in RT across UK

CBCT scans

1. Median from each scanner was use to define scanner average CTDIvol, DLP, scan length.
2. Third quartile (national reference) and median (achievable) of the scanner median data were calculated

Collected data

1. Protocol data
2. Patient sample data (average dose index)
3. Dosimetry information (measures in PMMA phantoms)

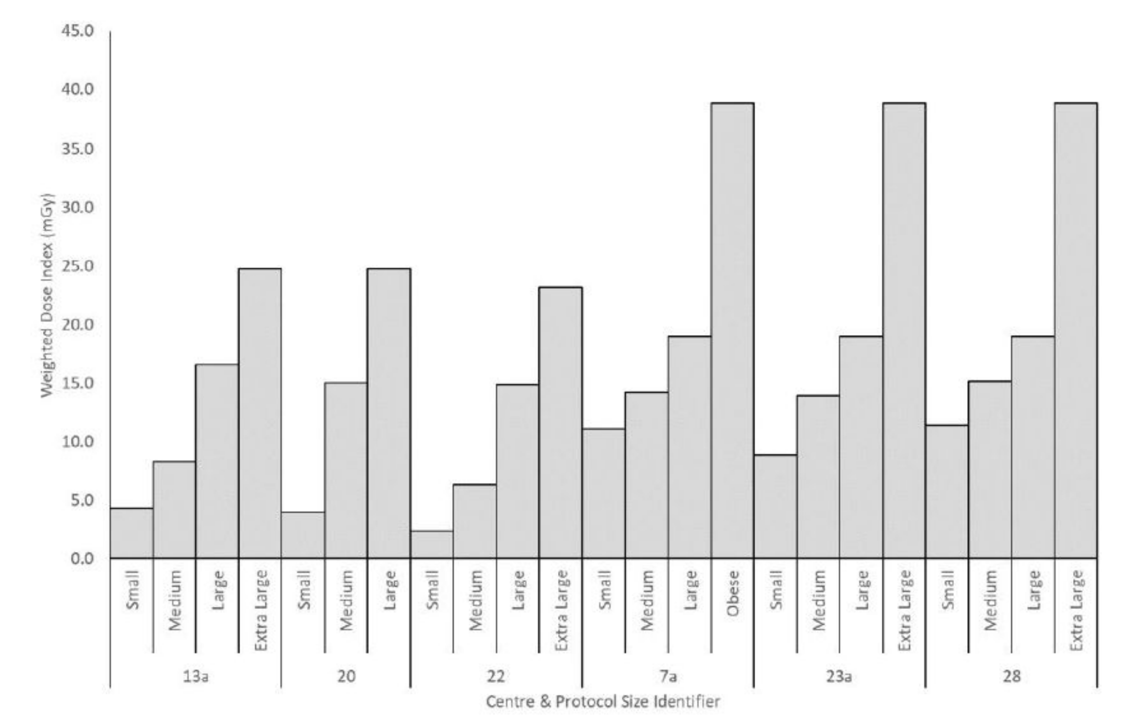
From Tim Wood, IPEM working group on dose optimisation

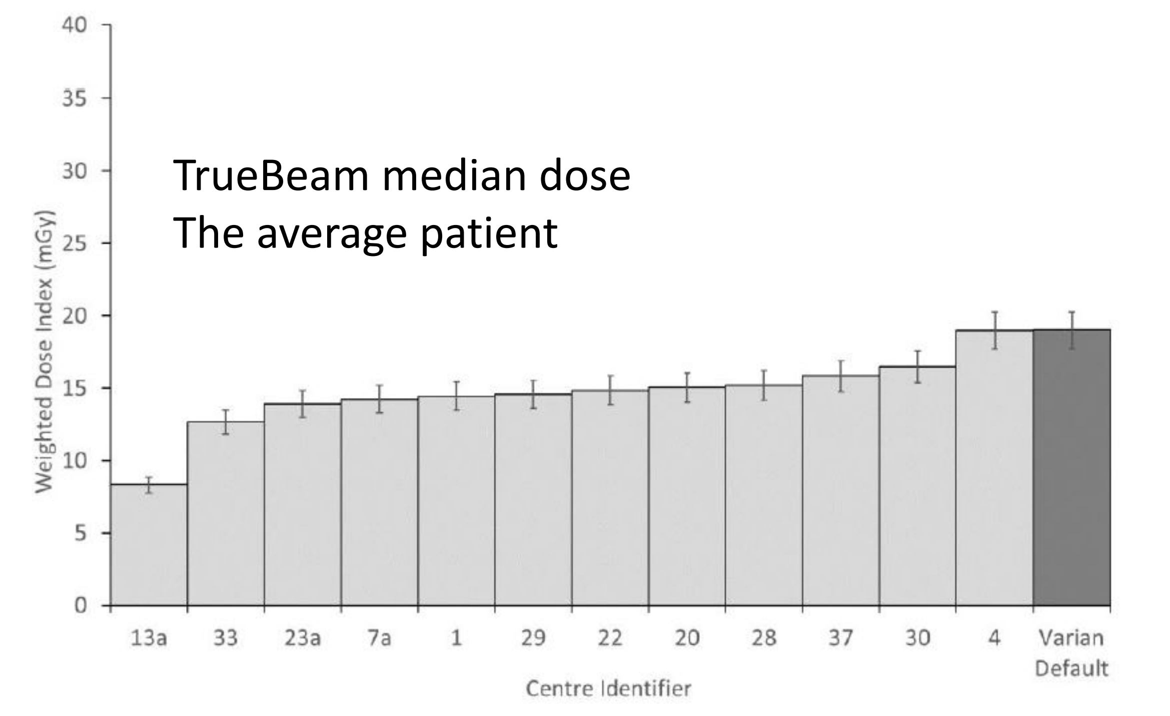
Protocol comparisons - prostate

13 centers using size based protocols.

9 centers using “obese” on an “as required” basis (most patients get the same exposure settings)

15 centers using a single mode (12 using Varian default settings)

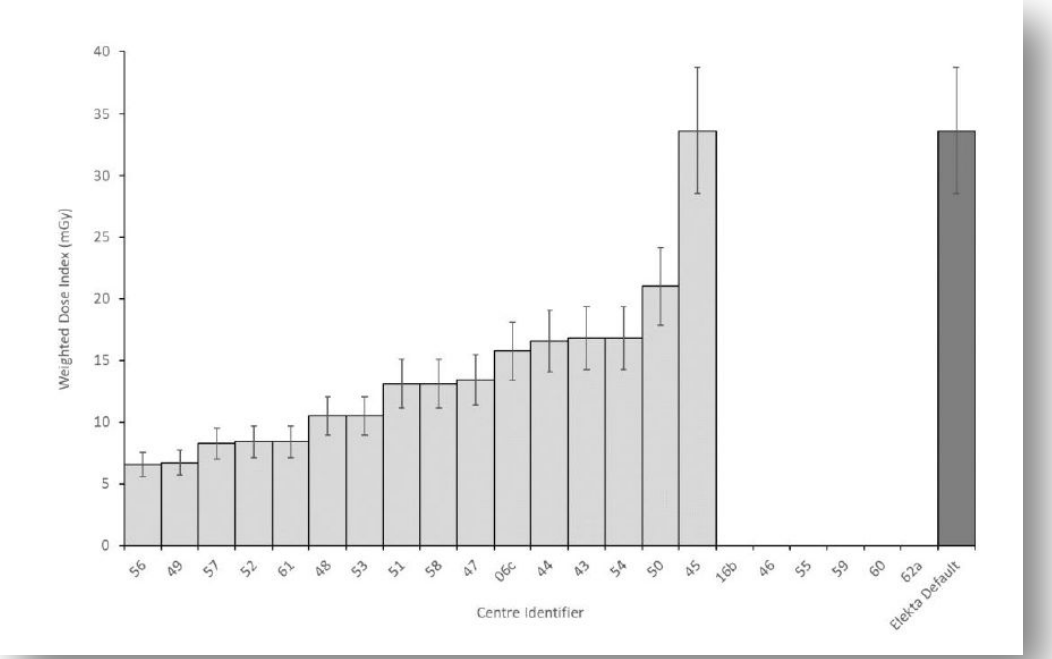


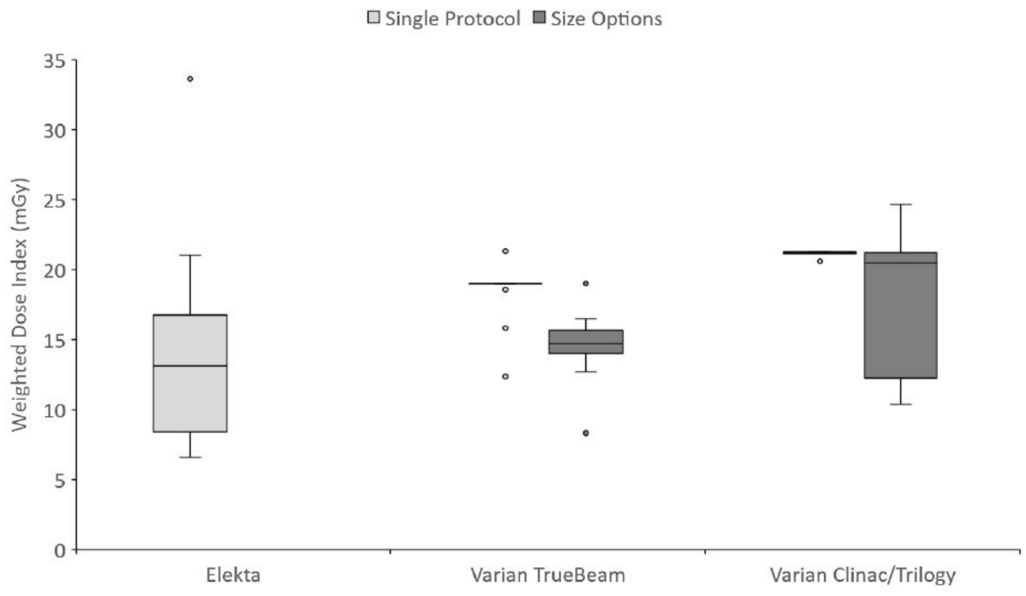


From Tim Wood, IPEM working group on dose optimisation

First audits of imaging dose to patients in RT across UK showed large variability

Protocol comparisons - prostate



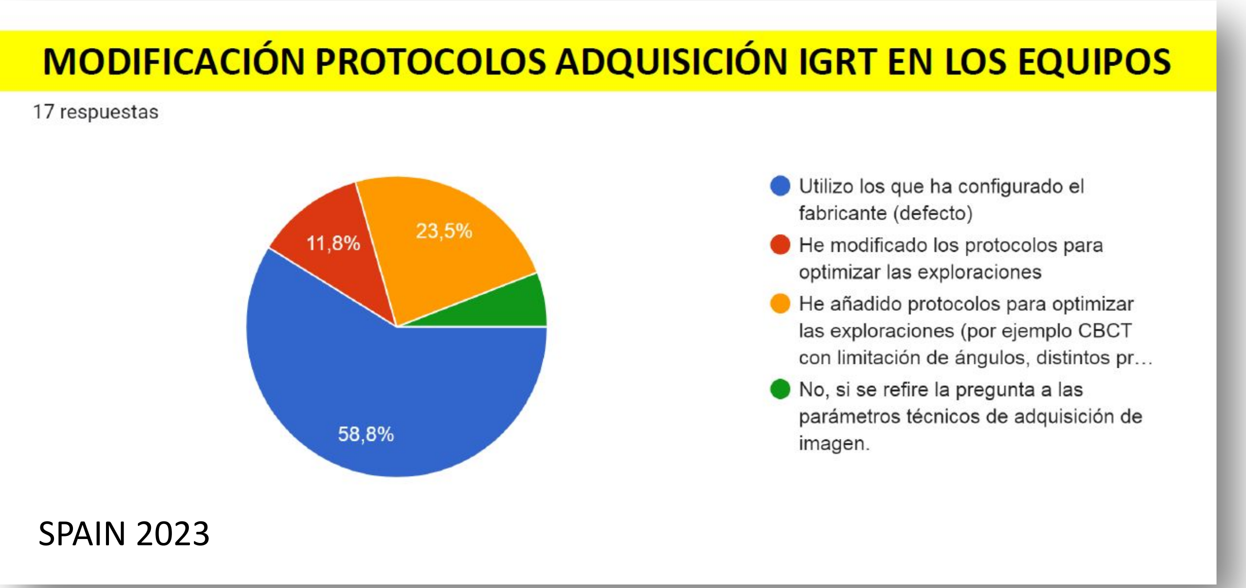


From Tim Wood, IPEM working group on dose optimisation

Surveys on dose optimisation in IGRT show that most departments use default CBCT settings

Only 39% centers have optimized exposure settings:

QUARTET



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Surveys on dose optimisation in IGRT show that most departments use default CBCT settings

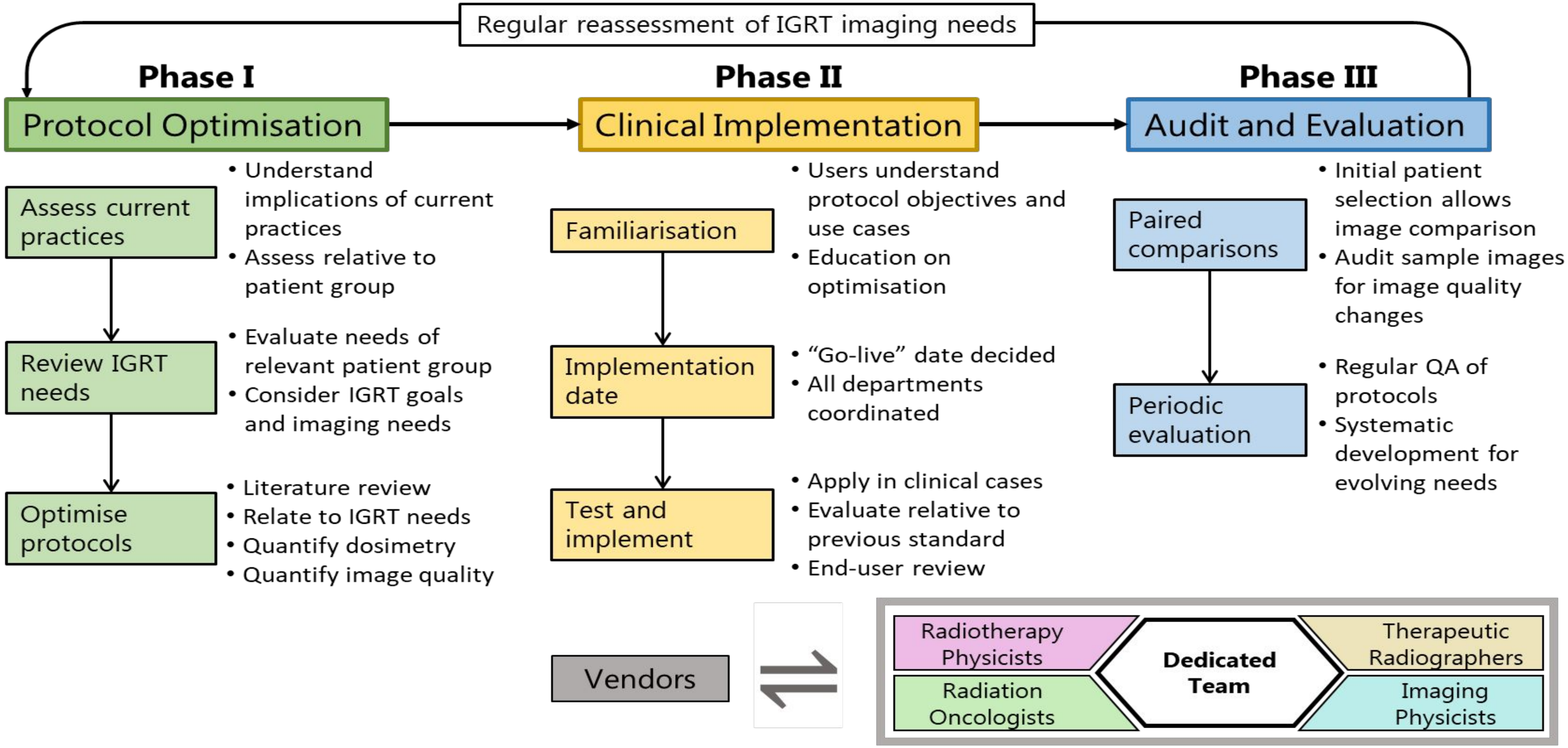
Despite the widespread use, we still **lack clear guidance** for optimisation and widely accepted frameworks for evaluating the quality and suitability of CBCT imaging protocols.

To address this gap, the 2022 ESTRO physics workshop focused on image-quality and imaging-dose optimisation for IGRT using CBCT.

Keep in mind

- Optimising imaging protocols to minimise the dose while maintaining acceptable image quality for clinical use is considered to fall specifically under the responsibility of medical physicists
- We stress here the importance of including RTTs and radiation oncologists in the IGRT imaging optimisation from the beginning
- Assessing the clinical and practical implications of image quality to avoid relying on quantitative indices, such as signal to noise ratio (SNR) or contrast to noise ratio (CNR), alone.

CBCT Optimisation: An Approach



Phase I: Protocol Optimisation

Step 1: Assess current practices

- Observation of current practice: image quality and dose implications
- Reviews should be organised by clinical indications
- Evaluate image quality applying robust standards agreed by all the team
  - Subjective: Grading image noise or quality of relevant clinical structures
  - Objective: Region of interest based measures of CT numbers and noise
- Dose review should assess dose indices such as CTDIs and DLPs for each protocol and how doses accumulate over the fractions. Compare with national DRLs

Phase I: Protocol Optimisation

Step 2: Review local IGRT needs

Evaluate the image quality needs for each clinical situation

If all patients achieve equal image quality irrespective of their size.

↓

The dose for thinner patients could be reduced

Phase I: Protocol Optimisation

Step 3: Optimise Protocols

- **Identify relevant literature**
- **Assess relevant literature:** Look at the methodologies for image optimization

Author / Year	Aim	Method	Dose assessment	System
Roxby et al. 2008	Dose reduction of CBCT for pelvis, addition of a Cu filter and mAs reduction	Image quality and noise assessed using CATPHAN Image quality evaluation on a series of 6 patients by RO (adequacy for outlining bladder, rectum, and prostate).	CTDIw using CTDI Perspex phantom 32 cm) with a calibrated Farmer type ionisation chamber	Varian trilogy
Ding et al. 2013	Comparison of imaging doses from MV images, kV radiographs, kV-CBCT	-	Monte Carlo techniques and treatment planning system for calculating doses to patient anatomy. kV and MV phase-space files calibrated for the specific imaging procedure. Plastic Water (LR)+Exradin A14 cylindrical ionisation chamber	Varian (OBI, TrueBeam)
Liao et al. 2015	Measurements of dose for different Elekta CBCT parameters (voltage, current, exposure time per frame, collimator and gantry rotation range)	No image quality analysis	CTDIair, CTDIw, and DLP using CT pencil ion chamber in air, head (16 cm) and body (32 cm) acrylic CTDI phantom	Elekta synergy with XVI 3.5 CBCT
Wood et al. 2015	To develop size-based radiotherapy kV CBCT protocols for pelvis	Image noise measured in an elliptical phantom of varying size for a range of exposure factors	PCXMC software	Varian
Elstrom et al. 2016	Evaluate the image quality in a standard QA phantom with both clinical and non-clinical acquisition modes and reconstruction methods	CATPHAN and relevant quantified metrics	-	Varian
Santoso et al. 2016	To investigate the effect of gantry speed on 4DCBCT image quality and dose	CATPHAN	CIRS Thorax phantom nd IBA CC13ion chamber	Varian

Author / Year	Aim	Method	Dose assessment	System
Mao et al. 2018 [19]	Optimised CBCT parameters for intracranial stereotactic radiosurgery	Quantitative image quality evaluation: CATPHAN 504 phantom assessing image quality metrics. Steev phantom CNR Patient images (1 patient)	Using Cone-beam dose index CTDI Head Phantom. Pencil ionisation chamber Measurement of wCBDI (conebeam dose index)	Varian Edge
Ding et al. 2018 [29]	General guidelines on dose management for different imaging types	-	-	-
Yang et al. 2018 [34]	Examine the impact of body size, radiation exposure and tissue type on the target detectability of CBCT imaging for the preset body scan protocols (Thorax, Pelvis, and Pelvis Obese)	Electron density phantom (model 062, VIRS), 18 cm diameter, with various bolus layers. CNR on the target ROI and background region.	CTDIw as displayed by the MDCT and CBCT	Varian TrueBeam STX
Liang et al. 2019 [24]	4D CBCT optimisation of intraftaction preset for stereotactic body radiotherapy lung patients (nominal Acquisition Interval) to have a good description of tumor motion and to reduce noise and the artifacts caused by MV scattered photons 4D CBCT acquired with the MV beam on.	CIRS Dynamic phantom to assess the accuracy of target motion using the various intrafraction presets. Qualitative image quality evaluation (blurring).	No dose evaluation	Elekta XVI 5.0
Xu et al. 2019 [20]	Study of the dosimetric effect of reducing kV imaging frequency for prone breast treatments. Frequency optimisation using CT patient anatomy and shifts from first 3 days.	No image quality evaluation	Dose reduction in % depending on the number of fractions with kV imaging	-
Chan et al. 2020 [26]	Optimisation of kV planar image exposure settings based on patient size (waist circumference)	Qualitative analysis by radiation therapists via questionnaire	-	Varian Trilogy iX

Author / Year	Aim	Method	Dose assessment	System
Agnew et al. 2020 [27]	Optimise patient dose and image quality of pelvis, thorax and head and heck images based on patient size	Quantitative image quality evaluation: Elliptical Perspex phantom of various dimensions with spaces for a circular polystyrene insert and CATPHAN 505 image quality phantom. Patient images scored by RTTs (grading quality on a scale from 1-5) and evaluated time needed to perform the match.	From literature	Varian TrueBeam
Ordonez-Sanz C et al. 2021 [17]	A simple method for optimising CBCT dose and image quality for pelvis treatment, based on patient-specific attenuation	Stratification of patients into four groups based on CTDIvol of the planning CT. Quantitative image quality evaluation using 4 phantoms (various sizes) CATPHAN+barts solid water and Vaseline bolus. CTDI matching those of the 4 patient groups. Patient evaluation (noise level in ROI in the bladder) + RTT and RO image quality scoring.	CTDIw using a 32 cm PMMA body phantom and a pencil chamber	Varian TrueBeams and Clinac iX
Khan et al. 2022 [16]	Implementation of optimised CBCT protocols for most tumour sites in adult patients	Qualitative analysis off and online using patient images using a scoring system and in comparison to Varian default protocols Image quality and clinical usability (accuracy of 3D registration)	CTDI in air using RaySafe X2-CT sensor and To CTDI phantom (CTDIw) (16 and 32 cm)	Varian TrueBeams
Martin and Abuhaimed (2022) [70]	Study of the impact of using standard protocols for imaging anatomical phantoms of varying size from a library of 193 adult phantoms. Shows the need for patient-size-specific protocols for dose optimization.	No image quality evaluation	Monte Carlo simulations to calculate organ and tissue doses. Results combined based on size-specific effective dose.	Varian TrueBeam

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Phase I: Protocol Optimisation

Step 3: Optimise Protocols

- **Identify relevant literature**
- **Assess relevant literature:** Look at the methodologies for image optimization
- **Identify proposed protocols:**
  - **Select relevant protocols :** Are they appropriate for clinical practice (patient population, treatment techniques, tumor sites)
  - **Develop imaging protocols locally:** This may involve phantom imaging. These phantoms should be representative of patient population.

Phase I: Protocol Optimisation_HSCSP

Step 3: Optimize protocols

Implementation of a comprehensive set of optimised CBCT protocols and validation through imaging quality and dose audit

[1]MARINA KHAN, BSc, [2]NAVNEET SANDHU, [2]MARIUM NAEEM, [2]REBECCA EALDEN, [2]MICHAEL PEARSON, [1]ABDIRZAK ALI, [2]IAN HONEY, [3]AMANDA WEBSTER, [2,4]DAVID EATON and [2,4,5]GEORGIOS NTENTAS, DPhil

CBCT Protocols	kV	mA	ms	f/s	Gantry speed (º/S)	Trajectory	Number of projections	mAs	CTDI in Air (mGy)	$CTDI_w$ (mGy)[a]	Change in $CTDI_{air}$ (%)
Varian_Abdo/ Pelvis	125	38	20	15	6	Full	900	684	42.8	11.5	n/a
Abdo/Pelvis_S	125	25	10	15	6	Full	900	225	15.7	4.2	−63%[d]
Abdo/Pelvis_M	125	38	20	15	6	Full	900	684	42.8	11.5	0%[d]
Abdo/Pelvis_L	125	60	20	15	6	Full	900	1080	66.3	17.9	55%[d]
Abdo/Pelvis_HD	125	38	20	15	3	Full	1800	1368	85.6	22.8	100%[d]

Phase I: Protocol Optimisation_HSCSP

Step 3: Optimize protocols

Optimisation of Varian TrueBeam head, thorax and pelvis CBCT based on patient size

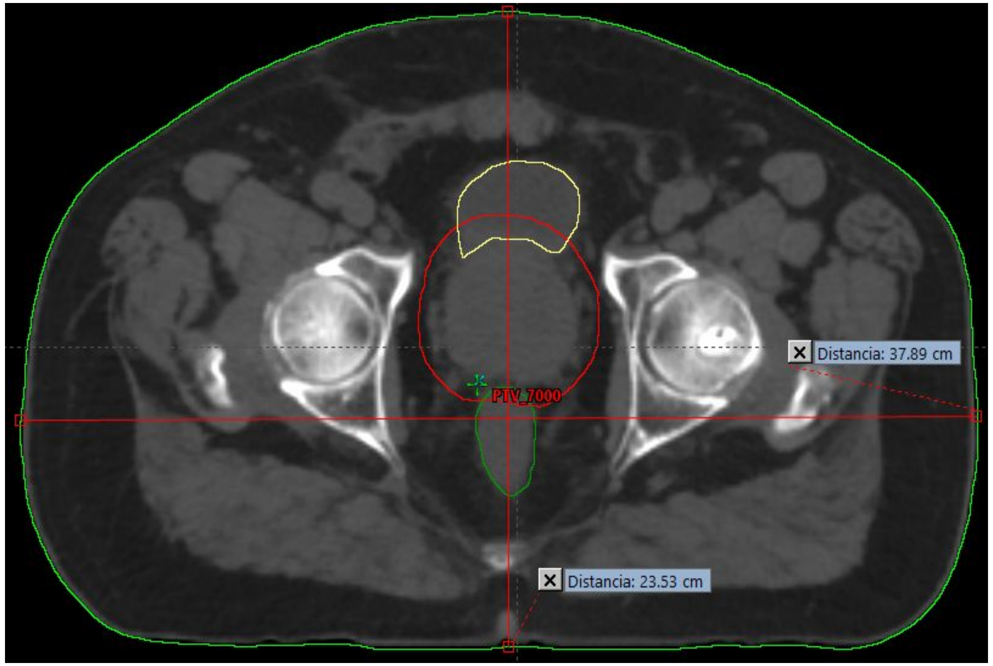
Christina E. Agnew[1], Candice McCallum[1], Gail Johnston[2], Adam Workman[2] and Denise M. Irvine[1]

	Pelvis (mAs)		Pelvis obese (mAs)	Khan values
Phase	Small	Medium	Large	
Default	125 kV, 1080 mAs		140 kV, 1680 mAs	
1	855	1080	1080	1080
2	630	855	1080	
3	427·5	630	1080	684
4	225	–	1080	225
Optimised mAs (% reduction from default)	225 (–80%)	855 (–20%)	1080 (–35%)	
Estimated dose reduction (cGy/image) determined from published data[6]	–0·8/1 –16·0/20	–0·2/1 –4·0/20	N/A	

Phase I: Protocol Optimisation_HSCSP

Step 3: Optimize protocols – patient stratification

$$mean\ diameter = \frac{max.\ AP\ diameter + max.\ LAT\ diameter}{2}$$



CBCT protocol	Mean diameter
Pelvis_S	≤26 cm
Pelvis_M	26-36 cm
Pelvis_L	≥36 cm

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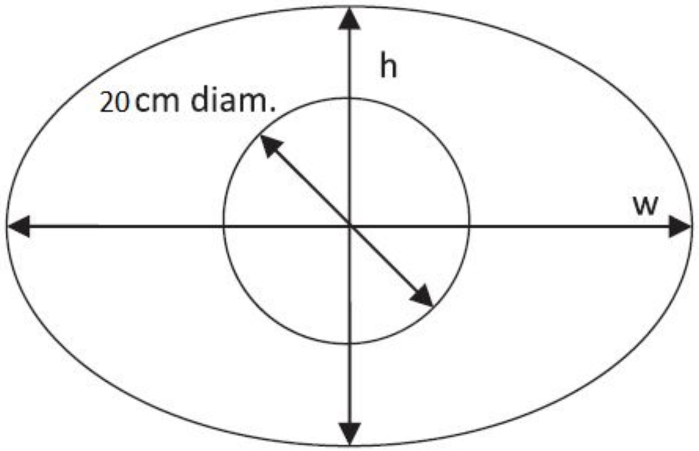
Image quality evaluation in a phantom

CATPHAN (Pelvis_S)

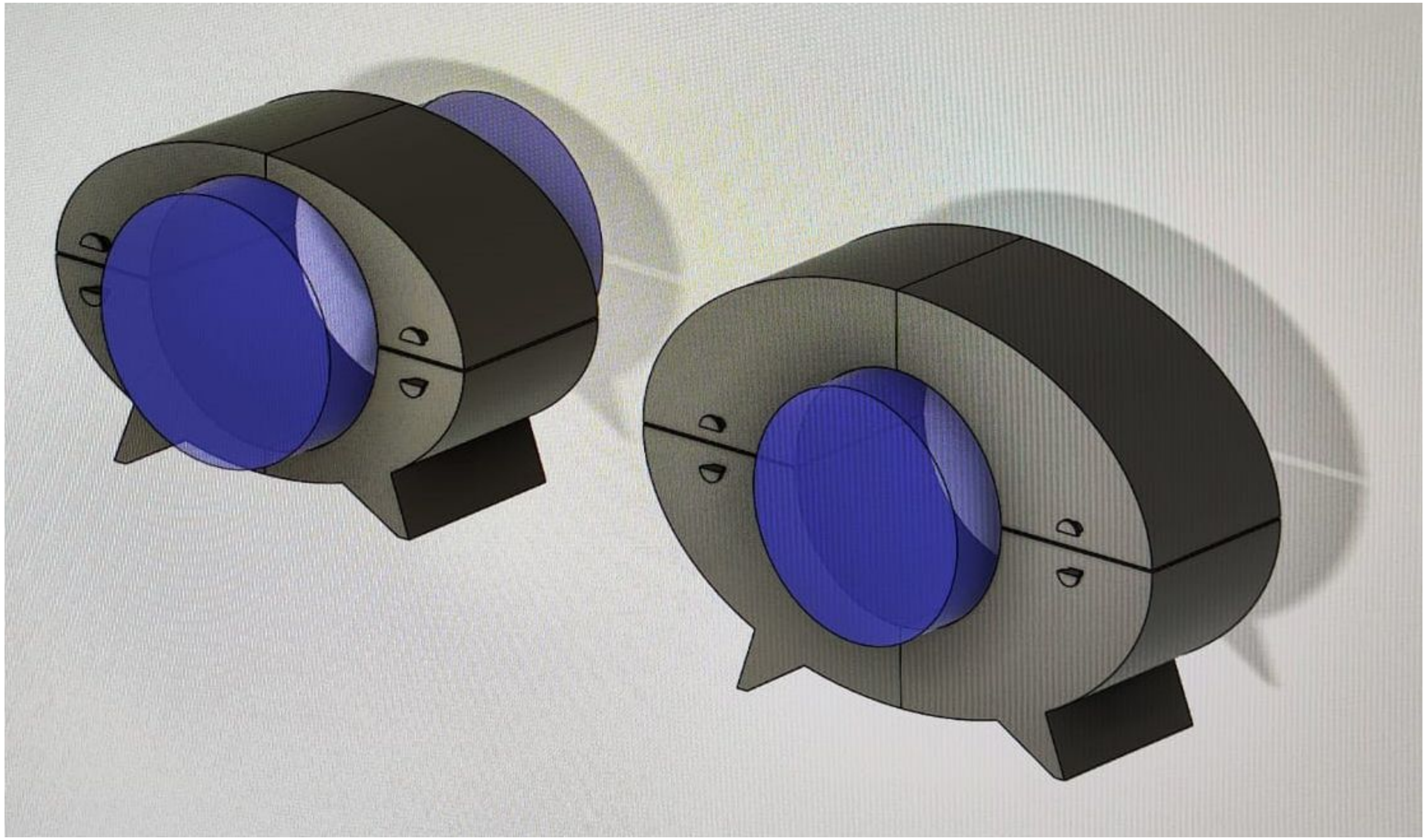
Solution: design phantoms mimicking different thickness in which CADPHAN can be inserted



Material	HU
PLA 90% (1)	-44,72
PLA 93% (1)	-36,80
PLA 93% (2)	-106,62
PLA 97% (2)	-48,97

Dimension Lab HSCSP

- medium: w=36 cm ; h=24 cm
- large: w=50 cm ; h=33 cm



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Phase I: Protocol Optimisation

Step 3: Optimise Protocols

- **Quantify local dosimetry:** Measure radiation dose indices for each proposed protocol
- **Quantify image Quality:**
  - Via phantom imaging tests.
  - On patient images (same patient different protocols)
- **Generate proposal:**
  - Provide an estimate of the potential dose reductions

Image quality evaluation in a phantom

Parameter		Measurement	Baseline	Difference	Status	Tolerances
	Geometric distortion (mm)	0,18	0,00	-0,18	✔ Passed	0,18; 0,5
	Spatial resolution (lp/mm)	0,33	0,31	-0,02	✔ Passed	0,17; 0,22; 0,33; 0,4; 0,45
	Uniformity (HU)	-2,63	0,00	2,63	✔ Passed	-30; -2,63; 30
	Contrast (units)	0,89	0,88	-0,01	✔ Passed	0,53; 0,89
	Noise (units)	5,43	5,97	0,54	✔ Passed	5,43; 7,16

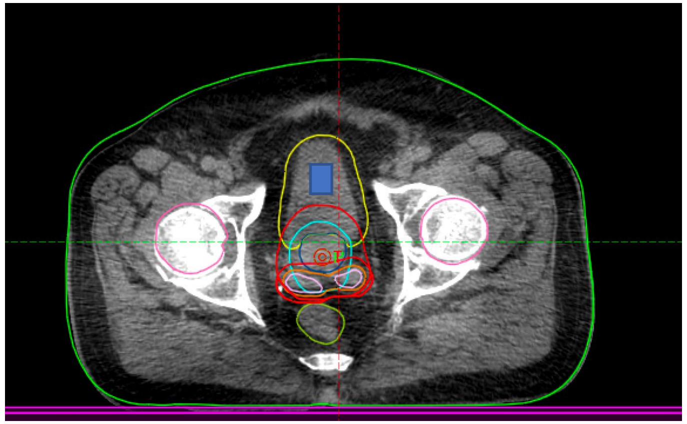
Image quality evaluation in a phantom

	Air (HU)	-999,68	-1.000,00	-0,32	✔ Passed	-1.050	-999,68	-950
	Teflon 'R' (HU)	976,27	964,00	-12,27	✔ Passed	914	976,27	1.004
	Delrin 'R' (HU)	363,88	350,00	-13,88	✔ Passed	300	363,88	400
	Acrylic (HU)	134,16	120,00	-14,16	✔ Passed	70	134,16	170
	Polystyrene (HU)	-29,60	-35,00	-5,40	✔ Passed	-85	-29,6	15
	Low density polyethylene (LDPE) (HU)	-85,92	-100,00	-14,08	✔ Passed	-150	-85,92	-50
	Polymethylpentene (PMP) (HU)	-180,73	-200,00	-19,27	✔ Passed	-250	-180,73	-150

Image quality evaluation patients

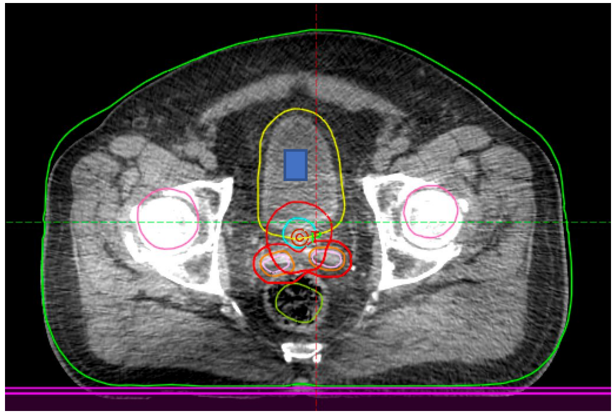
mAs decrease

1080 mAs



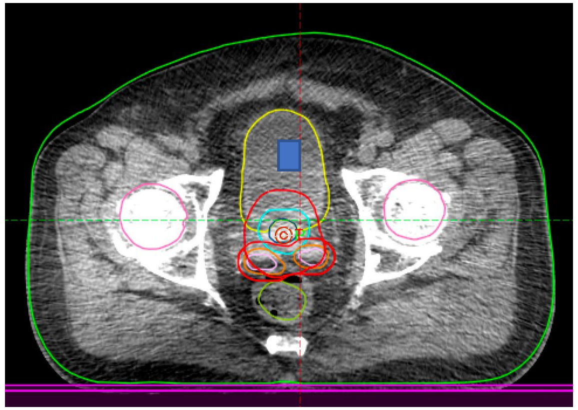
SD 26.3 MU

864 mAs



SD 34.3 MU

648 mAs



SD 46.4 MU

Noise increase

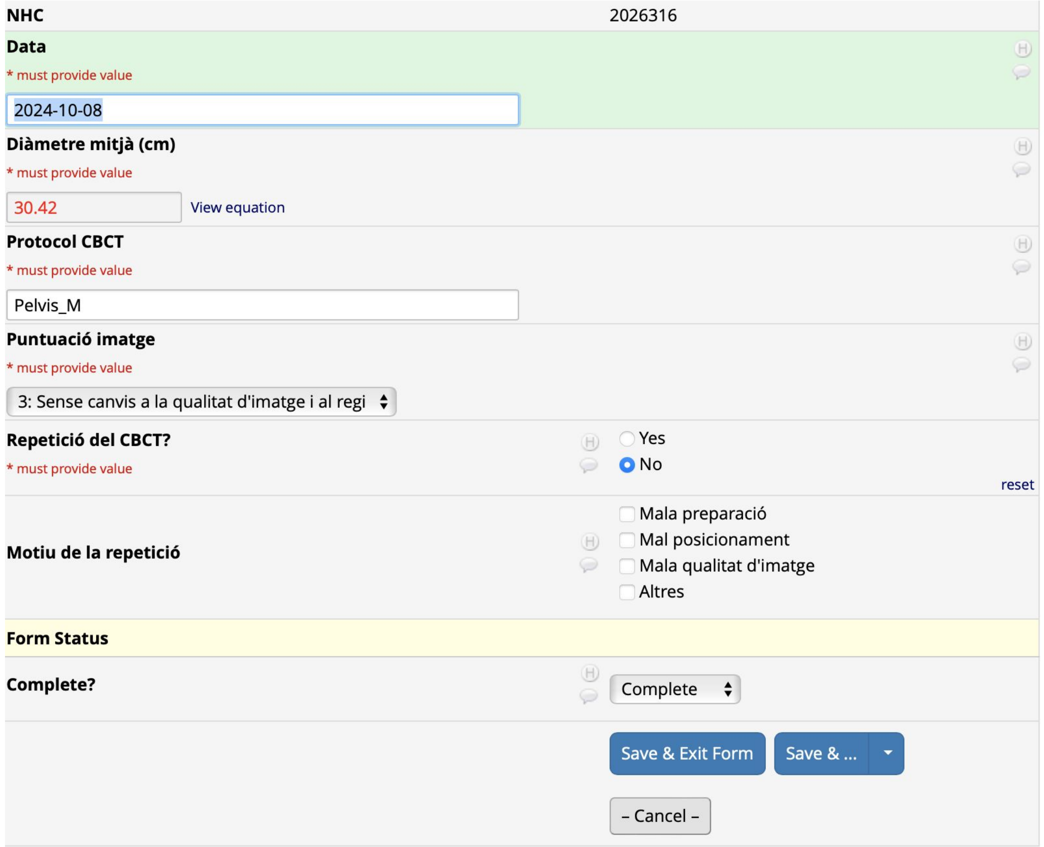
CTDI vol 16 mGy

CTDI vol 12.8 mGy

CTDI vol =9.6 mGy

Dose decrease

Image quality evaluation patients


NHC 2026316

Data
* must provide value
2024-10-08

Diàmetre mitjà (cm)
* must provide value
30.42 View equation

Protocol CBCT
* must provide value
Pelvis_M

Puntuació imatge
* must provide value
3: Sense canvis a la qualitat d'imatge i al regi

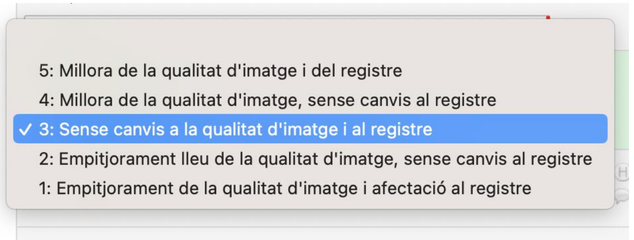
Repetició del CBCT?
* must provide value
Yes
No
reset

Motiu de la repetició
Mala preparació
Mal posicionament
Mala qualitat d'imatge
Altres

Form Status

Complete? Complete

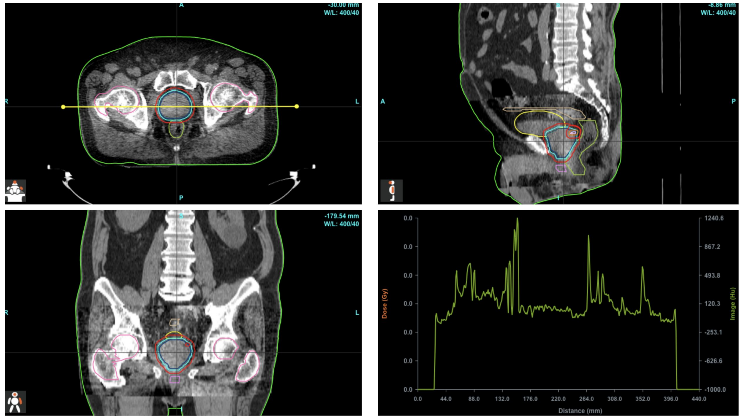
Save & Exit Form
Save & ...
– Cancel –


5: Millora de la qualitat d'imatge i del registre
4: Millora de la qualitat d'imatge, sense canvis al registre
✓ 3: Sense canvis a la qualitat d'imatge i al registre
2: Empitjorament lleu de la qualitat d'imatge, sense canvis al registre
1: Empitjorament de la qualitat d'imatge i afectació al registre

Dose calculation on CBCT Perfraction ™

mAs decrease

1080 mAs



Beams (2D)

BEAM NAME	ENERGY	PERCENT	POINTS	FAILED HIGH	FAILED LOW
1-181-179-0	6 MV	99.98 %	29,496	0	7
2-179-181-0	6 MV	99.89 %	29,544	0	33

Targets

CTV_7000 — 100.00 % Gamma

METRIC	TPS	QA	Δ%
Mean	2.50	**2.50**	0.11
D95	2.47	**2.47**	-0.04

CTV_5600 — 100.00 % Gamma

METRIC	TPS	QA	Δ%
Mean	2.38	**2.37**	-0.16
D95	1.99	**1.98**	-0.20

Prostate — 100.00 % Gamma

METRIC	TPS	QA	Δ%
Mean	2.50	**2.50**	0.07
D95	2.47	**2.47**	0.00

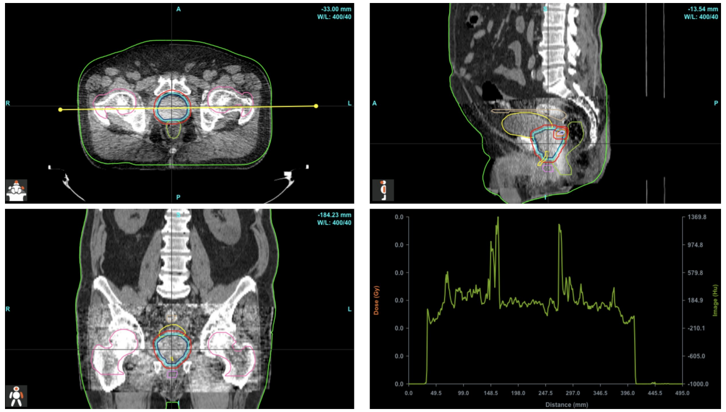
PT… — 10…

MI…

Me…

D9…

864 mAs



Beams (2D)

BEAM NAME	ENERGY	PERCENT	POINTS	FAILED HIGH	FAILED LOW
1-181-179-0	6 MV	99.87 %	29,492	0	39
2-179-181-0	6 MV	99.82 %	29,542	0	52

Targets

CTV_7000 — 100.00 % Gamma

METRIC	TPS	QA	Δ%
Mean	2.50	**2.47**	-1.23
D95	2.47	**2.42**	-1.81

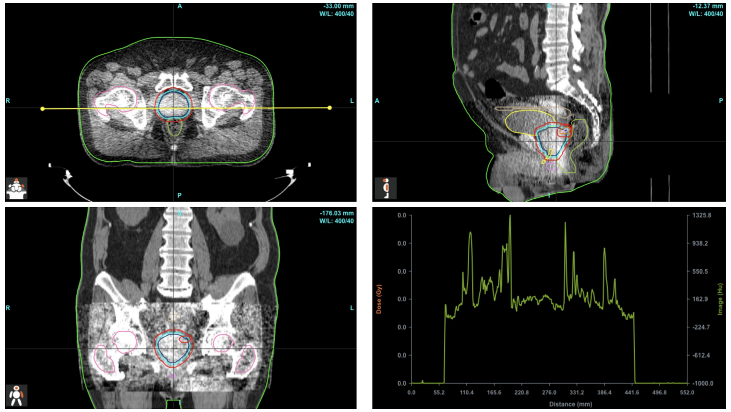
CTV_5600 — 100.00 % Gamma

METRIC	TPS	QA	Δ%
Mean	2.38	**2.32**	-2.43
D95	1.99	**1.93**	-2.66

Prostate — 100.00 % Gamma

METRIC	TPS	QA	Δ%
Mean	2.50	**2.47**	-1.19
D95	2.47	**2.43**	-1.69

648 mAs



Targets

CTV_7000 — 100.00 % Gamma

METRIC	TPS	QA	Δ%
Mean	2.50	**2.43**	-2.63
D95	2.47	**2.39**	**-3.03**

CTV_5600 — 100.00 % Gamma

METRIC	TPS	QA	Δ%
Mean	2.38	**2.30**	**-3.31**
D95	1.99	**1.92**	**-3.36**

Prostate — 100.00 % Gamma

METRIC	TPS	QA	Δ%
Mean	2.50	**2.44**	-2.63
D95	2.47	**2.40**	-2.94

Hospital de la Santa Creu i Sant Pau

Phase II: Clinical implementation

Step 4: Testing

- Test new protocols for a small number of patients on one of the linacs
    - 5 patients for each new protocol (include patients of various sizes for one-size fits all protocols
    - Select patients in the middle of treatment course so that new protocols can be compared with the previous protocols
    - Clinical team should be involved to evaluate image quality (on line and off line)

Phase II: Clinical implementation

Step 5: Familiarisation

- Communicate to all RTTs in the team.
  - Names of new protocols
  - Objectives and intended use of each of the protocols
  - Robust methods for selecting the appropriate protocol

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Conclusions

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Optimisation should be a continuous process taking into account the patient cohort advances in technology and the purpose of imaging

Optimisation is a multidisciplinary effort

Image quality has to be assessed taking into account registration accuracy, visualisation of volumes of interest and accuracy of dose calculation (if used for dose assessment)