Royal Berkshire
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Accuracy in Radiotherapy

Dr Sarah Osman

Royal Berkshire Cancer Centre
Medical Physics

20 May 2021

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Compassionate | Aspirational | Resourceful | Excellent

Contents

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- Radiotherapy for Treating Cancer
- Ionizing Radiation Regulations
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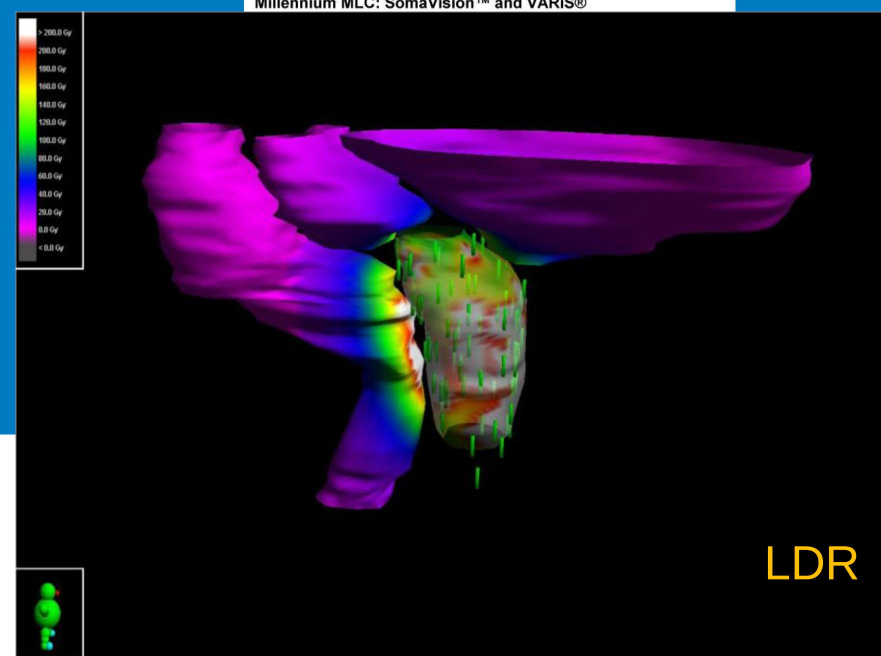
Clinical Importance

- 1 in 2 people will develop some form of cancer during their lifetime.
- >50 % will require RT at some point during their treatment
- Forms part of curative treatment in 40 % of cancer patients
  - Adjuvant setting – after surgery
  - Neoadjuvant setting – before surgery
  - Radical – stand alone
  - Chemo-radiotherapy

Radiotherapy Modalities

- External beam therapy (**EBRT**)
  - **Photons**
  - **Electrons**
  - Protons
  - Other particles

- Internal/surface therapy
  - **Brachytherapy**
  - Radiopharmaceuticals



Safety Critical Environment

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legislation.gov.uk

STATUTORY INSTRUMENTS

2017 No. 1075

HEALTH AND SAFETY

The Ionising Radiations Regulations 2017

Made - - - -	*27th November 2017*
Laid before Parliament	*30th November 2017*
Coming into force - -	*1st January 2018*

The Secretary of State makes these Regulations in exercise of the powers conferred by sections 15(1), (2), (3)(a) and (c), (4)(a), (5)(b), (6)(b) and (9), 18(2)(za), 43(2), (4), (5) and (6), 52(2) and (3), 80(1) and 82(3)(a) of, and paragraphs 1(1) and (2), 3 to 9, 11, 13, 14, 15(1), 16, 20 and 21(**a**) and (**b**) of Schedule 3 to, the Health and Safety at Work etc. Act 1974(**1**) ("the 1974 Act").

The Secretary of State makes these Regulations for the purpose of giving effect without modifications to proposals submitted by—

STATUTORY INSTRUMENTS

2017 No. 1322

HEALTH AND SAFETY

The Ionising Radiation (Medical Exposure) Regulations 2017

Made - - - -	*20th December 2017*
Laid before Parliament	*22nd December 2017*
Coming into force - -	*6th February 2018*

The Secretary of State, being the Minister designated(**1**) for the purposes of section 2(2) of the European Communities Act 1972(**2**) in relation to safety measures in regard to radioactive substances and the emission of ionising radiation, in exercise of the powers conferred by that section and by section 56 of the Finance Act 1973(**3**), makes the following Regulations. Regulation 4 and Schedule 1 (the Licensing Authority) are made with the consent of the Treasury.

Care Quality Commission
The independent regulator of health and social care in England

IRR and IR(ME)R

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Application

3.—(1) Subject to the provisions of this regulation and to regulation 5(1), these Regulations apply to—

(a) any practice; and

(b) any work (other than a practice) carried on in an atmosphere containing radon 222 gas at an annual average activity concentration in air exceeding 300 Bq m^{-3}.

(2) The following regulations do not apply where the only work being undertaken is that referred to in paragraph (1)(b), namely regulations 24, 28 to 31, 33 and 34.

(3) The following regulations do not apply in relation to persons undergoing medical exposures, namely regulations 8, 9, 12, 17 to 19, 24, 26, 32(1) and 35(1).

(4) Regulation 12 does not apply in relation to carers and comforters.

(5) In the case of a classified outside worker (working in a controlled area situated in Great Britain) employed by an employer established in Northern Ireland or in another member State, it is sufficient compliance with regulation 22 (dose assessment and recording) and regulation 25 (medical surveillance) if the employer complies with—

(a) where the employer is established in Northern Ireland, regulations 21 and 24 of the Ionising Radiations Regulations (Northern Ireland) 2000(**1**) or any other provision made for the purpose of implementing the relevant parts of Chapter VI of the Directive in Northern Ireland; or

(b) where the employer is established in another member State, the legislation in that State implementing the relevant parts of Chapter VI of the Directive where such legislation exists.

Application

3. These Regulations apply to the exposure of ionising radiation in England and Wales and Scotland—

(a) to patients as part of their own medical diagnosis or treatment;

(b) to individuals as part of health screening programmes;

(c) to patients or other persons voluntarily participating in medical or biomedical, diagnostic or therapeutic, research programmes;

(d) to carers and comforters;

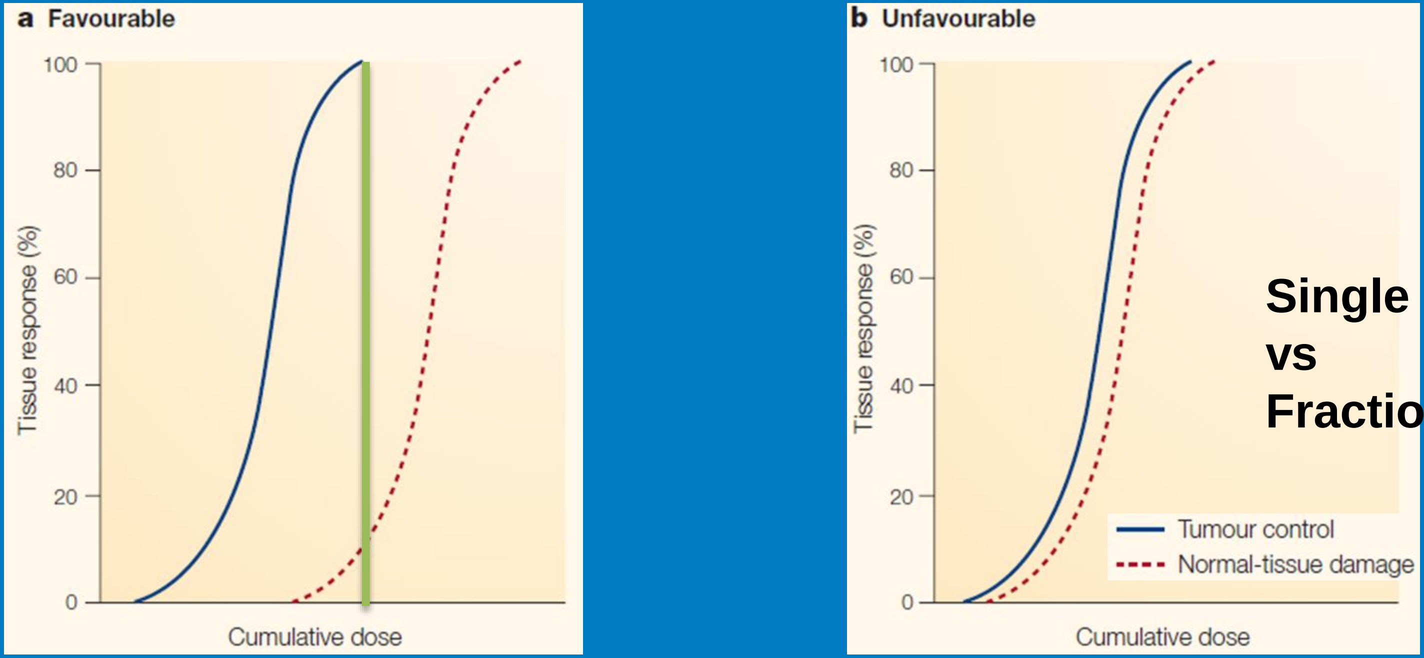
(e) to asymptomatic individuals;

(f) to individuals undergoing non-medical imaging using medical radiological equipment.

- **<u>Minimising</u> unintended, excessive or incorrect medical exposures**
- **<u>Justifying</u> each exposure to ensure the benefits outweigh the risks**
- **<u>Optimising</u> diagnostic doses to keep them "as low as reasonably practicable" for their intended use**

Aim of Treatment

- Clear relationship between tumour control probability and absorbed dose
- Dose-response curve has a sigmoid shape



Single dose vs Fractionation

Jacques Bernier, Eric J. Hall and Amato Giaccia

NATURE REVIEWS | CANCER 2004

There is considerable radiobiological evidence that tumour are dead only when every single colonogenic cell has been eliminated

Clinical trials and adoption of clinical protocols implicitly rely on the consistency of dose measurement

Lack of standardisation of dose measurements means treatments may not meet the requirements set out by the International Commission on Radiation Units and Measurements (ICRU)

NPL: Codes of Practice (CoP)

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Physics in Medicine & Biology

PAPER

IPEM code of practice for high-energy photon therapy dosimetry based on the NPL absorbed dose calibration service

David J Eaton[1,8], Graham Bass[2,8], Paul Booker[3,8], John Byrne[4,8], Simon Duane[2,8], John Frame[5,8], Mark Grattan[6,8], Russell AS Thomas[2,8], Natalie Thorp[3,8] and Andrew Nisbet[7,8]

Published 21 September 2020 • © 2020 Institute of Physics and Engineering in Medicine

Physics in Medicine & Biology, Volume 65, Number 19

Citation David J Eaton *et al* 2020 *Phys. Med. Biol.* **65** 195006

Physics in Medicine & Biology

The IPEMB code of practice for the determination of absorbed dose for x-rays below 300 kV generating potential (0.035 mm Al - 4 mm Cu HVL; 10 - 300 kV generating potential)

Prepared by a Working Party of the IPEMB with the following members: S C Klevenhagen (Chair)[1], R J Aukett[1], R M Harrison[1], C Moretti[1], A E Nahum[1] and K E Rosser[1]

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Physics in Medicine & Biology, Volume 41, Number 12

The IPEM code of practice for electron dosimetry for radiotherapy beams of initial energy from 4 to 25 MeV based on an absorbed dose to water calibration

IPEM Working Party: D I Thwaites (Chair)[1], A R DuSautoy[1], T Jordan[1], M R McEwen[1], A Nisbet[1], A E Nahum[1] and W G Pitchford[1]

Published 3 September 2003 • Published under licence by IOP Publishing Ltd

Physics in Medicine & Biology, Volume 48, Number 18

The National Physical Laboratory

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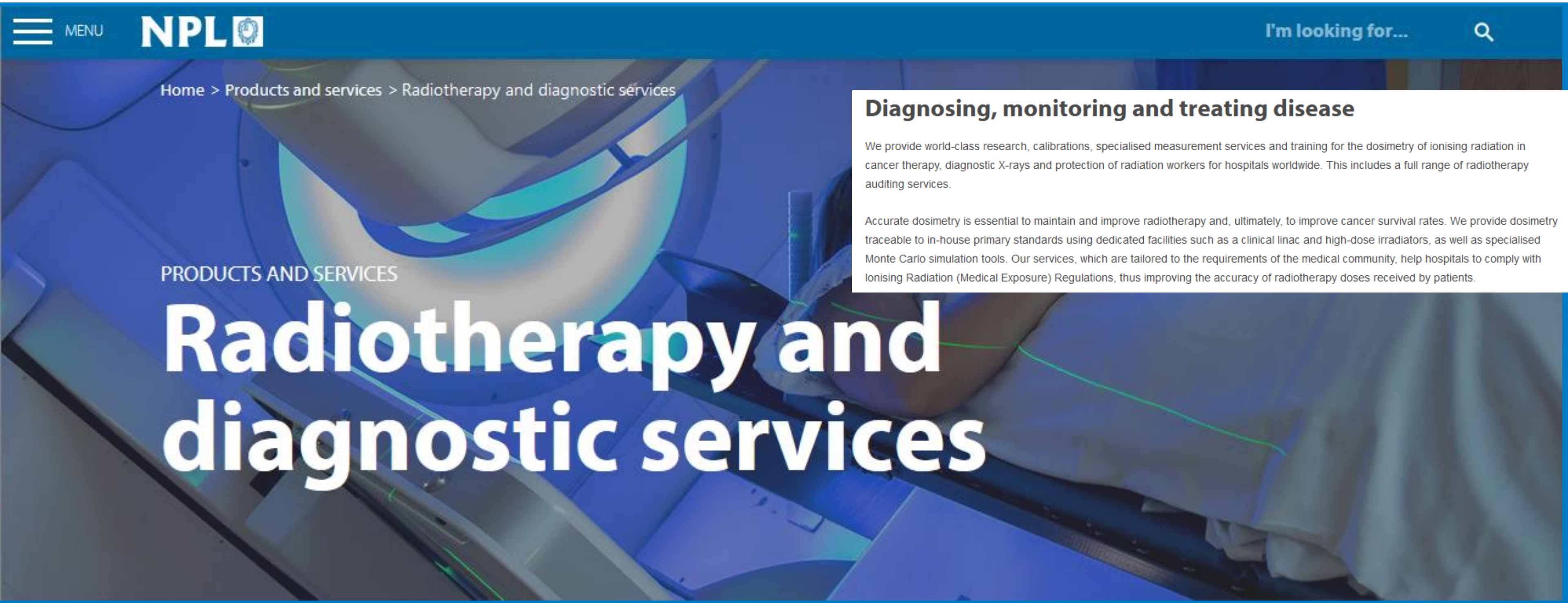
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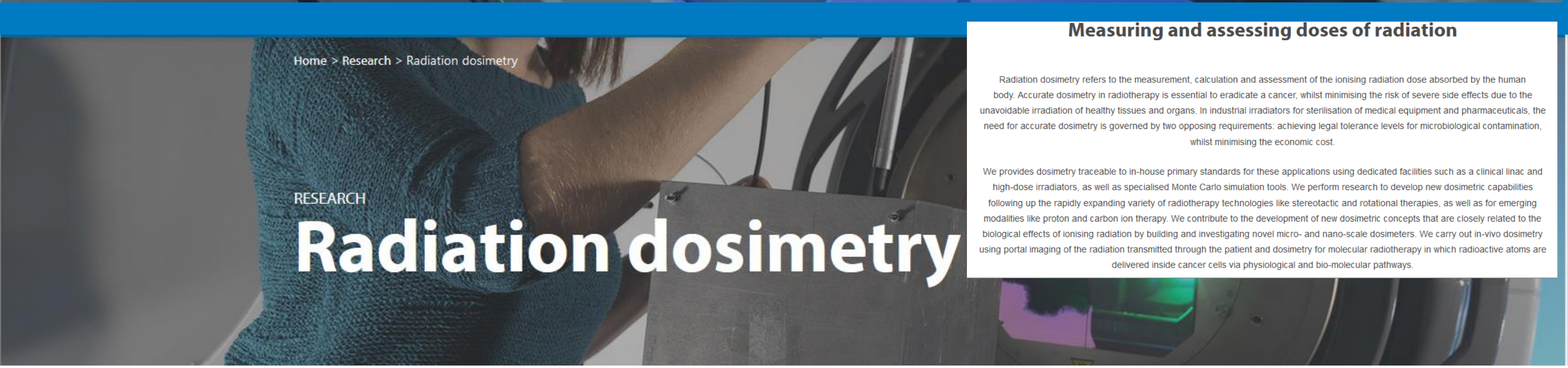
PRODUCTS AND SERVICES

Radiotherapy and diagnostic services

Diagnosing, monitoring and treating disease

We provide world-class research, calibrations, specialised measurement services and training for the dosimetry of ionising radiation in cancer therapy, diagnostic X-rays and protection of radiation workers for hospitals worldwide. This includes a full range of radiotherapy auditing services.

Accurate dosimetry is essential to maintain and improve radiotherapy and, ultimately, to improve cancer survival rates. We provide dosimetry traceable to in-house primary standards using dedicated facilities such as a clinical linac and high-dose irradiators, as well as specialised Monte Carlo simulation tools. Our services, which are tailored to the requirements of the medical community, help hospitals to comply with Ionising Radiation (Medical Exposure) Regulations, thus improving the accuracy of radiotherapy doses received by patients.


Home > Research > Radiation dosimetry

RESEARCH

Radiation dosimetry

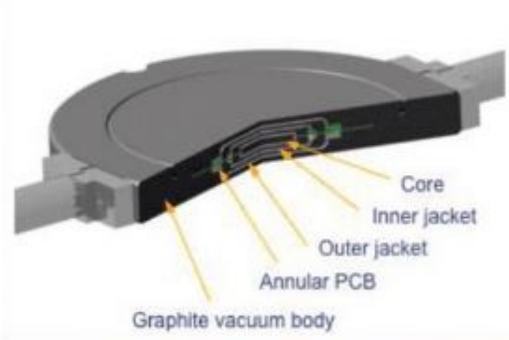
Measuring and assessing doses of radiation

Radiation dosimetry refers to the measurement, calculation and assessment of the ionising radiation dose absorbed by the human body. Accurate dosimetry in radiotherapy is essential to eradicate a cancer, whilst minimising the risk of severe side effects due to the unavoidable irradiation of healthy tissues and organs. In industrial irradiators for sterilisation of medical equipment and pharmaceuticals, the need for accurate dosimetry is governed by two opposing requirements: achieving legal tolerance levels for microbiological contamination, whilst minimising the economic cost.

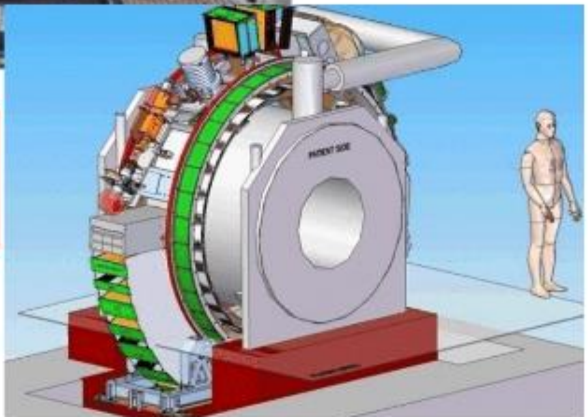
We provides dosimetry traceable to in-house primary standards for these applications using dedicated facilities such as a clinical linac and high-dose irradiators, as well as specialised Monte Carlo simulation tools. We perform research to develop new dosimetric capabilities following up the rapidly expanding variety of radiotherapy technologies like stereotactic and rotational therapies, as well as for emerging modalities like proton and carbon ion therapy. We contribute to the development of new dosimetric concepts that are closely related to the biological effects of ionising radiation by building and investigating novel micro- and nano-scale dosimeters. We carry out in-vivo dosimetry using portal imaging of the radiation transmitted through the patient and dosimetry for molecular radiotherapy in which radioactive atoms are delivered inside cancer cells via physiological and bio-molecular pathways.

NPL Medical Radiation Sciences

Methodology and technology standards for the safe and effective use of ionizing radiation in medical practice



- Development of Primary Standards
- Traceability chain
- Radiotherapy facility commissioning
- National Audits
- Development of Code of Practice
- Medical Physics training
- Support implementation of new RT modalities



Slide courtesy Miriam Barry (NPL)

NPL: Traceability Chain

- NPL uses a graphite calorimeter as the UK primary standard of absorbed dose determination.
- Calibration of hospital’s secondary standards
- Inter-comparison in local beam quality

6.1.1. The international measurement system

The international measurement system for radiation metrology provides the framework for consistency in radiation dosimetry by disseminating to users calibrated radiation instruments that are traceable to primary standards (Fig. 19). The BIPM was set up by the Convention of the Metre (Convention du Mètre, signed in 1875) with the aim of ensuring worldwide uniformity in metrology [48].

In radiation dosimetry, the primary standards dosimetry laboratories (PSDLs) of many States of the Metre Convention have developed primary standards for radiation measurements. Primary standards are instruments of the highest metrological quality that permit determination of the unit of a quantity according to its definition, the accuracy of which has been verified by comparison with standards of other institutions of the same level, i.e. with those of the BIPM and other PSDLs.

NPL: Audit

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National Physical Laboratory

Summary of results

The SABR lung audit results up until April 2020 have been summarised in order to quantify in a simple manner, whether the calculated dose distributions were delivered to the intended place and with the intended absolute dose and dose distribution. Results have been graded using a traffic light system for each metric as follows:

Alanine dosimetry

The difference between the output corrected alanine measured and TPS doses in the lung SABR plan was a mean of **+0.29%**.

Film dosimetry

The mean difference between film measured and calculated dose within the 100% isodose was: **-1.76%**.

Mean DTA

The mean distance to agreement for the TPS calculated and measured 50% isodose was **0.93 mm**.

Centre-of-mass difference

The centre of mass of the film within the 100% isodose was **0.46 mm** different compared to the TPS.

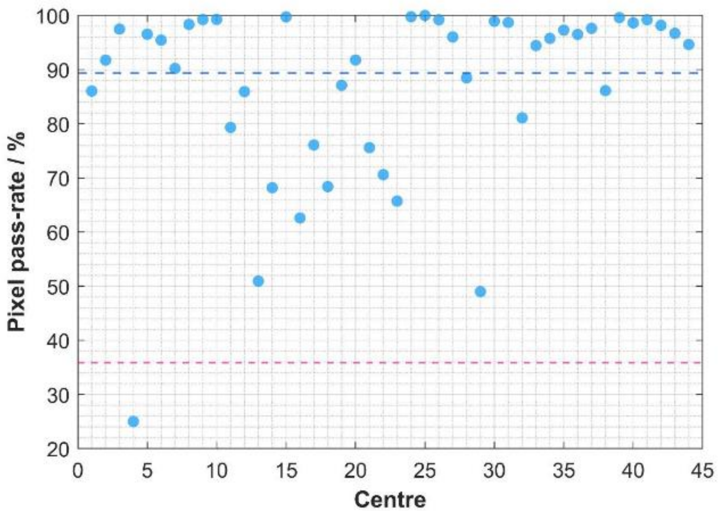

Figure 1. Passing rates for 3%/2mm, 50% of prescription lower threshold. Global gamma normalised to prescription dose.

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Radiotherapy Process and Accuracy Challenges

Radiotherapy process

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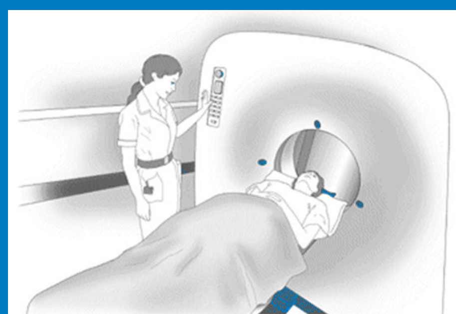
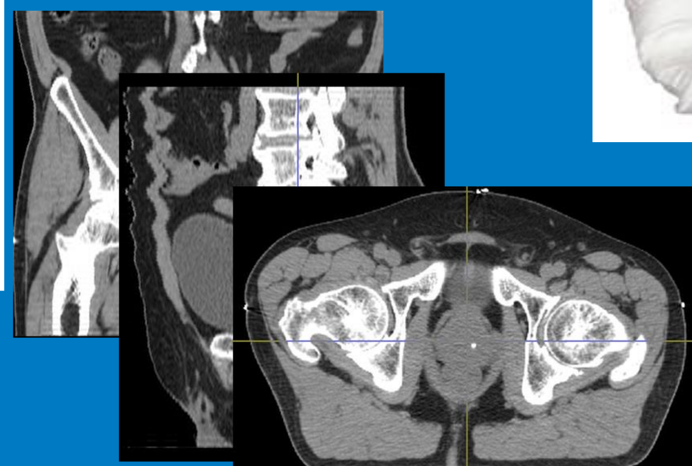
Diagnosis	screening	testing	confirmation	
Patient assessment	staging	Status Age	Treatment decision	
	pCT 4DCT			
Imaging and simulation	MRI	tumor segmentation	margin application	
	PET			
Treatment plan	Dose cloud	dvh/PAF/ complexity	Pre-treatment QA	In-vivo dosimetry
Treatment	IGRT	Image registration	Verify and record	
Outcome	Follow up	Local Control	QoL	

Radiotherapy process

Imaging and simulation

- Immobilization
- Imaging (scan type/range , Fiducial markers, drinking protocol, breathing instructions)





Which patients will benefit/tolerate extra measures?
Cost vs benefit

Radiotherapy process

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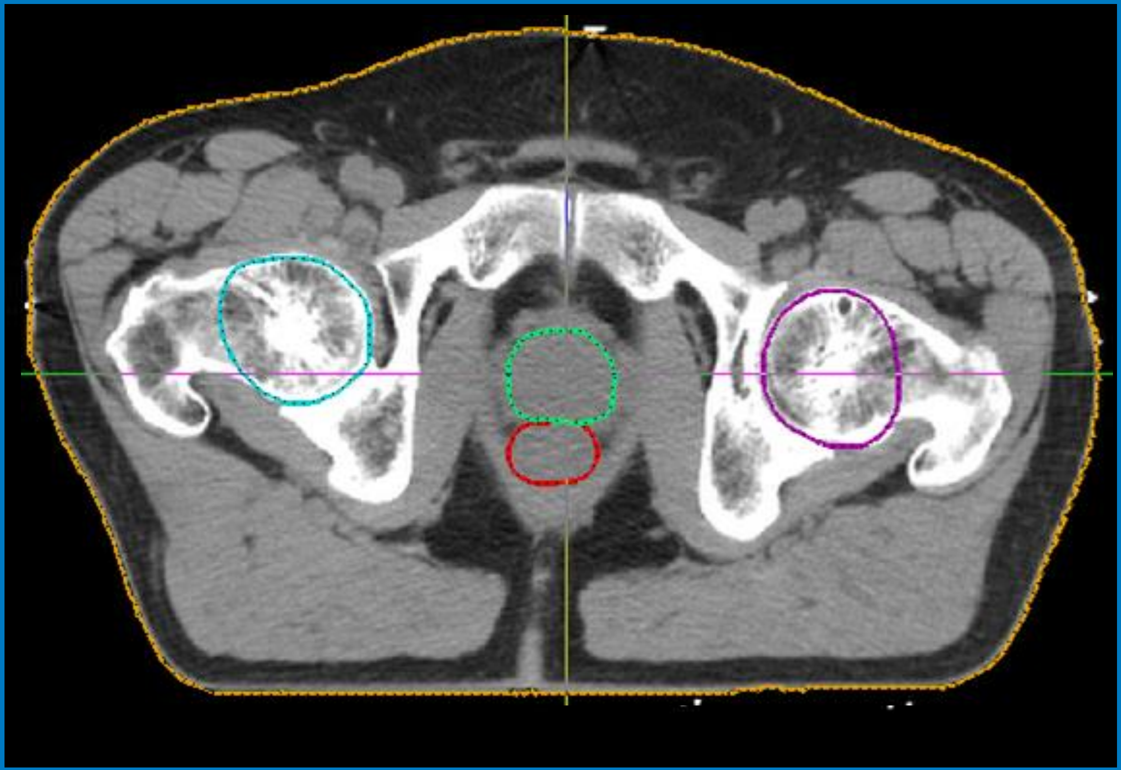
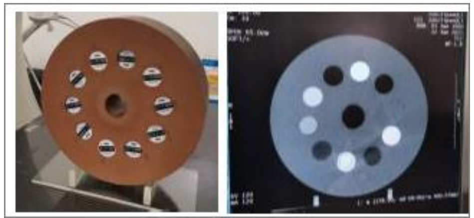
Imaging and simulation



Mechanical
Optical
Imaging checks



Target delineation errors?

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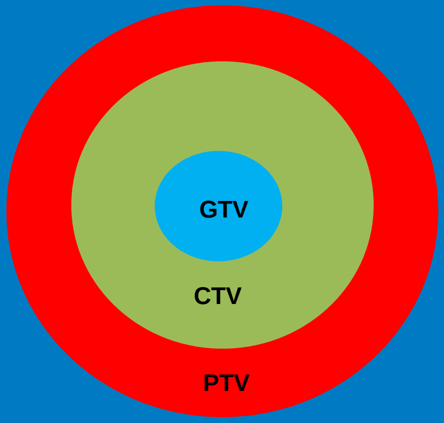
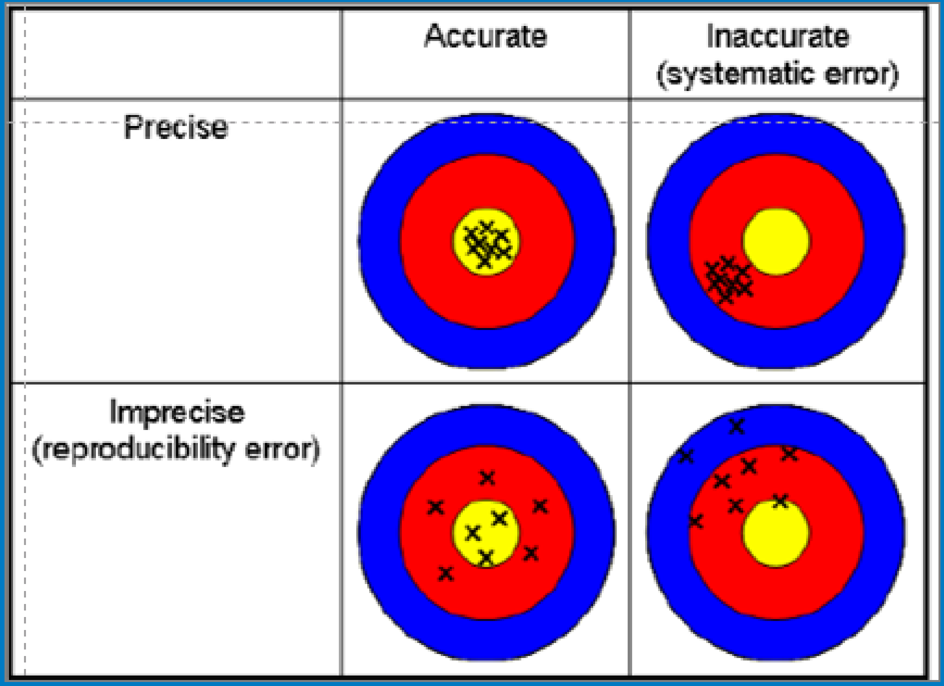
Imaging and simulation

Safety margins



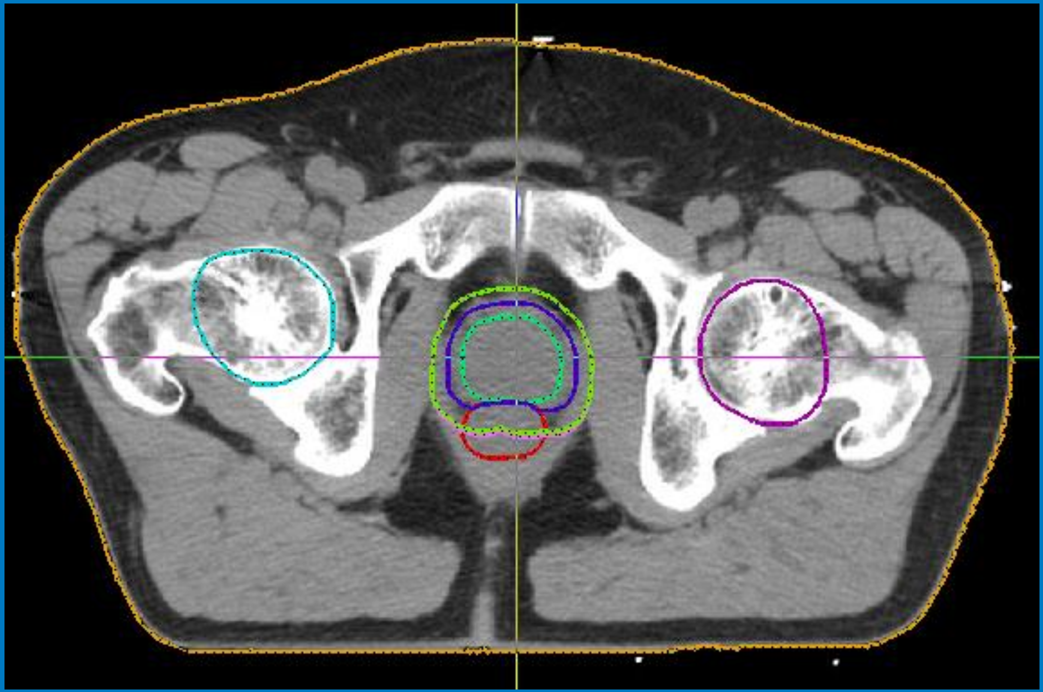


GTV = gross tumour volume
CTV = clinical target volume
PTV = planning target volume

$$M = 2.5\Sigma + 0.7\sigma$$

Van Herk et al, IJROBP 47(4) 1121-1135, 2000

Treatment plan



Ready for Treatment Planning

Plotting tanks for beam models

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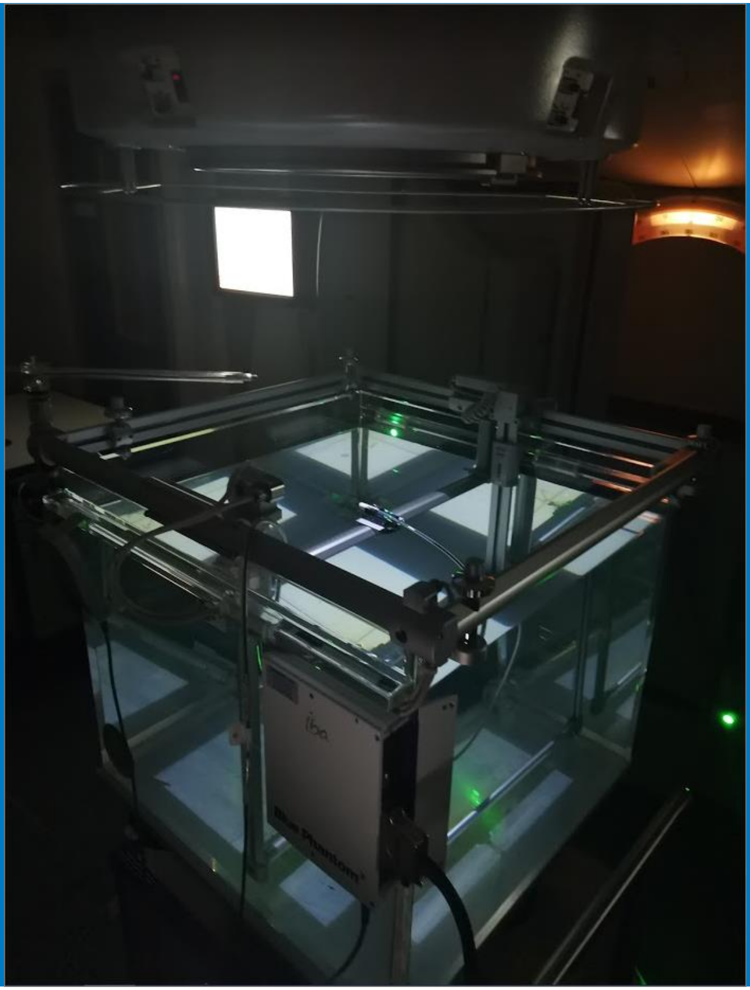

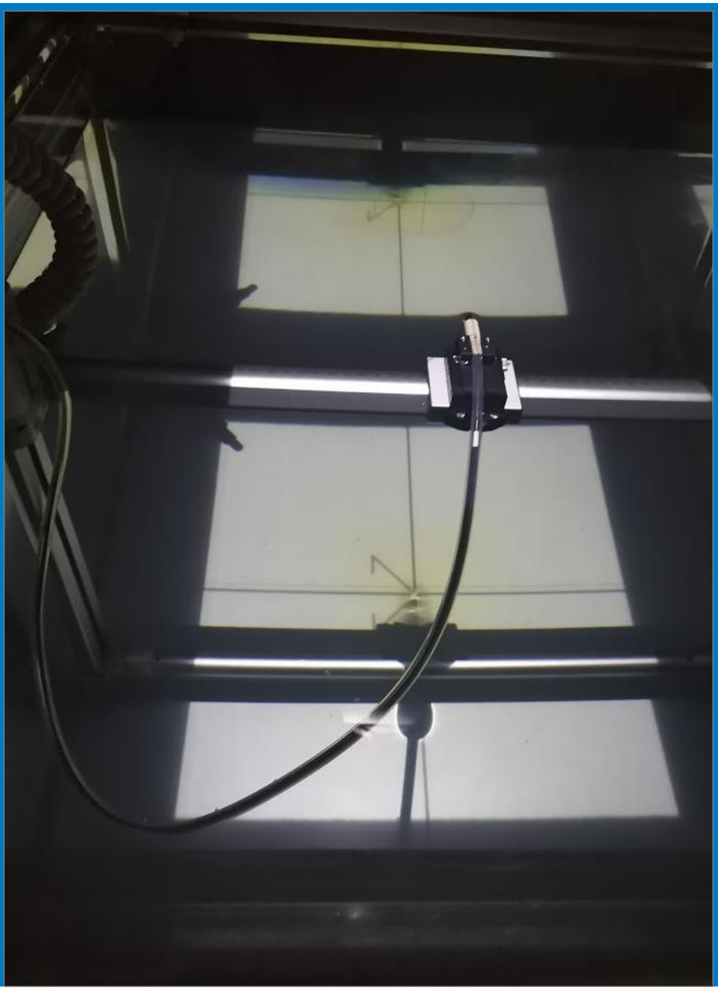

Treatment Planning Systems

Beam data routinely checked

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Schuster diode array

Radiotherapy process

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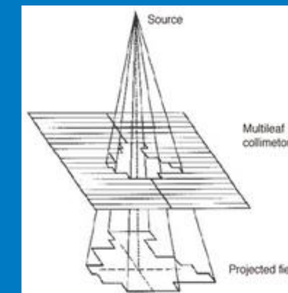
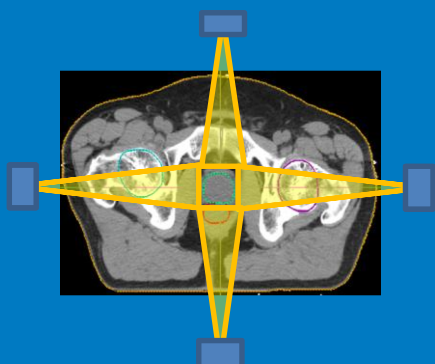
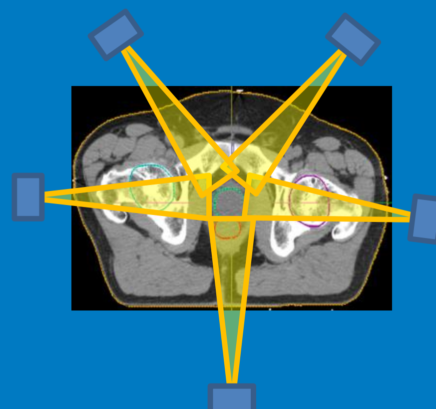
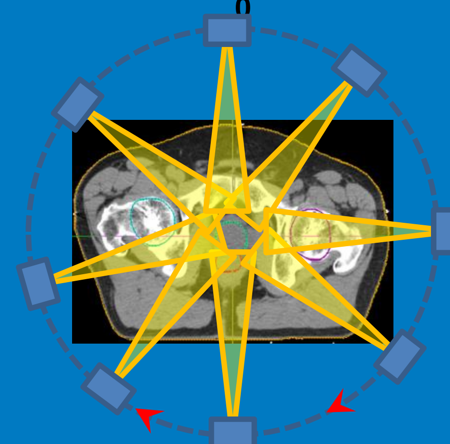
Treatment planning









Conformal
3D-CRT

Intensity Modulated
IMRT

Rotational
VMAT

Patient Specific QA (PSQA)

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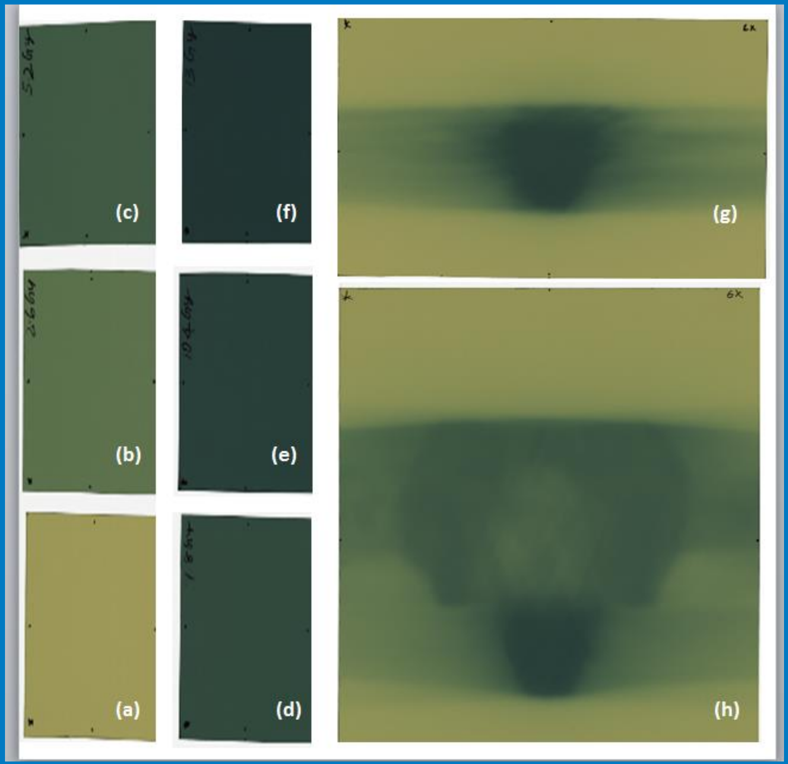
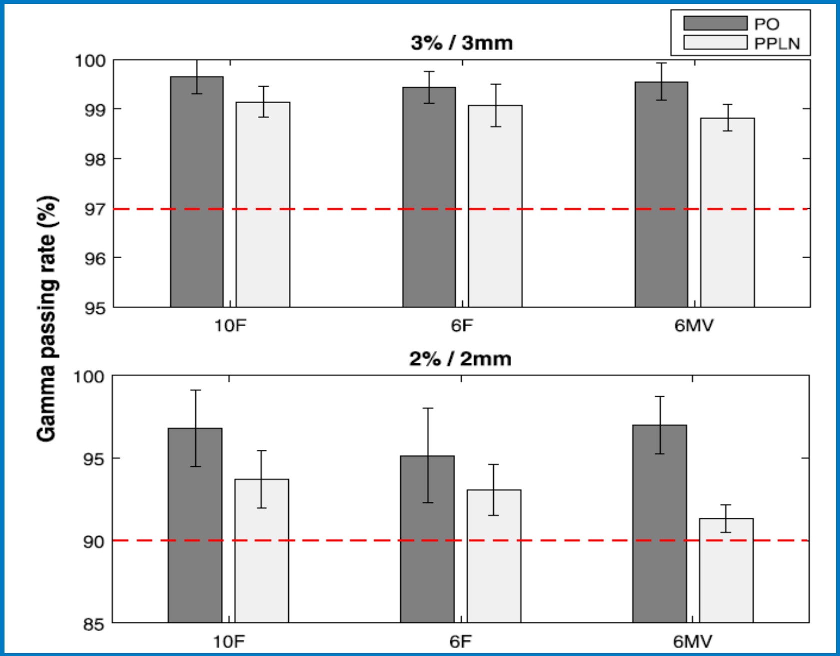
Film Dosimetry

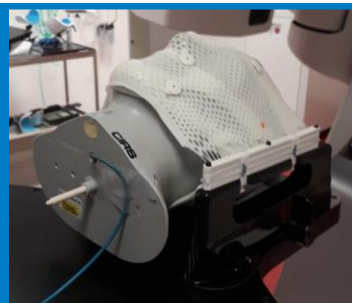


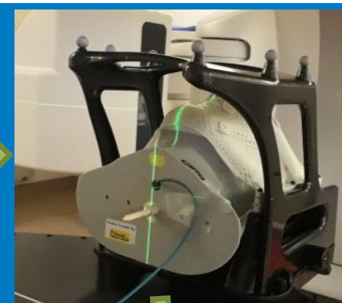
Gamma Analysis

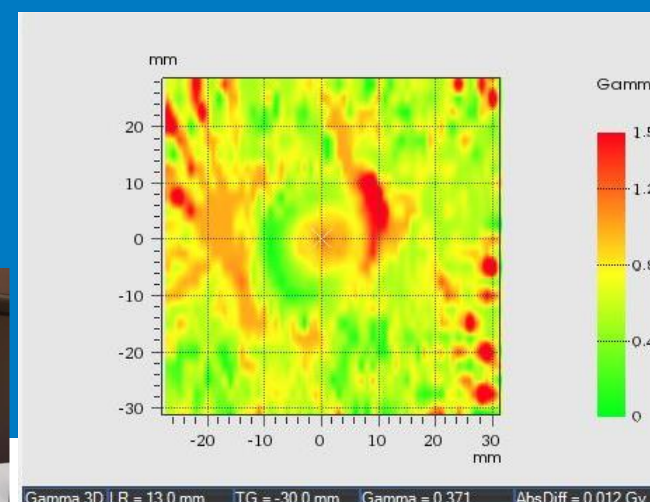
Compares dose from TPS vs Delivered

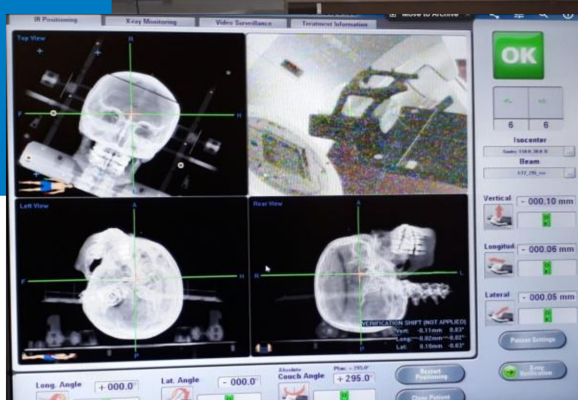


Radiosurgery for Brain Metastases PSQA









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Radiotherapy process

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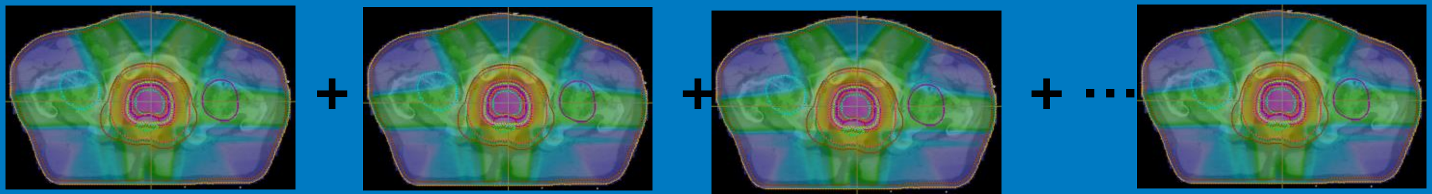
Treatment

Image Guided Radiation Therapy (IGRT)

- Online or Offline
  - Planar kV and/or MV
  - CBCT
  - MRI (MRI Linacs)
- Apply shifts or re-plan



$d_1 + d_2 + d_3 + \cdots d_n$

Planned vs delivered dose

Outcome

- **Local control**
- **Quality of life (QoL)**
  - treatment side-effects (**toxicity**)
- **Survival**
  - Disease-free survival (DFS)
  - Recurrence-free survival (RFS)
  - Overall survival (OS)

- **Minimise, Justify and Optimise doses to keep them "as low as reasonably practicable" for their intended use BASED ON EVIDENCE**

Conclusion

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- **Accuracy is key in evidence based precision medicine**
- **This is critical when dealing with ionizing radiation**
- **CoP and TG reports provide clear guidance on how to improve the accuracy of radiotherapy**
- **Local rules, clear WI and reporting are also very important**
- **Direct benefit for the patients, health workers and the public**
- **Standardization and harmonization to help us improve for future patients**