Next Generation Radiation Protection Research

Out-of-field dosimetry in radiotherapy for input to epidemiological studies

Roger Harrison

Chair, EURADOS Working Group 9: Radiation Dosimetry in Radiotherapy
Radiotherapy

A key component of cancer therapy

- approximately 14 million new cancer cases per year worldwide

- about half of all cancer treatments will involve radiotherapy (in the developed world)

- approx. 1.3 million RT treatments y\(^{-1}\) in EU

- Very large world wide radiotherapy patient cohort


doi:10.1038/nrclinonc.2010.135
Recent developments have improved target dose distributions:

- Intensity Modulated Radiotherapy
- Tomotherapy
- Image Guided Radiotherapy

**BUT:**
Radiotherapy also involves the irradiation of all parts of the body including healthy tissues and organs.

Source: Philips Healthcare

Total marrow irradiation protocol
From: Beavis AW
Radiotherapy modalities:

All have different implications for out-of-field doses

“conventional” linear accelerator

Tomotherapy

Robotic arm systems

GammaKnife

Brachytherapy

Proton therapy
Doses from radiotherapy & imaging systems

CT

On board imaging: kV and MV imaging systems on a linear accelerator
PET in the management of locally advanced and metastatic NSCLC. Willem Grootjans, Lioe-Fee de Geus-Oei, Esther G. C. Troost, Eric P. Visser, Wim J. G. Oyen & Johan Bussink

Adaptive radiotherapy planning using serial FDG-PET–CT imaging in a patient with stage IIIB NSCLC.
Why generate the complete dose specification from therapy and imaging?

• To inform risk/benefit considerations for the benefit of patients

• For input to epidemiological studies of risks, benefits and outcomes
  o Second cancers
  o Cardiovascular disease
  o Other organ damage

• To study the effects of ionising radiation on humans, following on from the Japanese LSS

The out-of-field dose to the patient from all sources - “the complete dose specification” ……………..

A complex synthesis of therapy and imaging exposures from numerous modalities and techniques
Four important attributes in the design of epidemiological studies of radiation-exposed populations*:

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2.5
Equivalent Dose / Sv

Cancer risk

Japanese LSS data
bystander effects
LNT
threshold
cell kill

Schematic dose-risk graph (after Hall 2008)

Equivalent Dose / Sv
Cancer risk

Japanese LSS data

Equivalent Dose / Sv

0.01  0.05  2.5  10
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<td>4. Potential value of the study as determined by public health, clinical,</td>
<td>Clinical need and basic radiation protection requirement for risk/benefit judgements</td>
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EURADOS Working Group 9: Radiation Dosimetry in Radiotherapy

- Development of “the complete dose specification” from all sources of radiation to all parts of the body, delivered as part of radiotherapy planning & treatment

- Develop & harmonise out-of-field dosimetry techniques in radiotherapy

- Provide dosimetric input to second malignancy risk models and epidemiological studies
Measuring out-of-field doses from a paediatric brain tumour treatment (photons)

Institute of Nuclear Physics (IFJ) and Centre of Oncology, Krakow
Ruđer Bošković Institute, Clinical Hospital for Tumours & Clinical Hospital Centre, Zagreb
Measuring out-of-field doses from a paediatric craniospinal treatment (photons)

Cranio-spinal irradiation at the Centre for Oncology, Krakow, and the Clinical Hospital for Tumours, Zagreb Passive detectors (TLD, RPL) positioned inside 5y and 10y old phantoms.
Measuring out-of-field doses from a paediatric brain tumour treatment using Gamma knife™ (stereotactic radiosurgery)

Ruđer Bošković Institute, Clinical Hospital for Tumours & Clinical Hospital Centre Zagreb 2014
BOMAB (Bottle Manniquin Absorber) phantom experiments:

University of Pisa & University Hospital of Santa Chiara, Pisa, 2011, 2012

Institute of Nuclear Physics (IFJ) and Centre of Oncology, Krakow 2011, 2012

Out-of-field dose differences between phantom measurements and calculation using a treatment planning system
Some preliminary results........

Out-of-field dose measurement in a paediatric anthropomorphic phantom

10y IMRT treatment of paediatric brain tumour
Out-of-field dose measurement in a paediatric anthropomorphic phantom

10y IMRT treatment of paediatric brain tumour

Dose range of interest: ~ 10 – 1000 mGy

Dose (GY) for 40 Gy to target
Paediatric brain tumour treatment (photons)

Dose comparison for 5y phantom
Total target dose = 40 Gy
Paediatric brain tumour treatment (photons)

**IMRT**: total target dose = 40 Gy

![Bar chart showing dose distribution for various organs and tissues during brain tumour treatment using IMRT.]
Proton therapy dosimetry:

Institute of Nuclear Physics (IFJ), Krakow

- Out-of-field doses in a water tank
- Brain tumour treatment simulation
- Environmental neutron measurements with a variety of dosemeters
Schematic view of ten measurement positions around a 10-year-old paediatric phantom and experimental setup with Bonner spheres within the CCB-Krakow gantry room.

A comprehensive spectrometry study of stray neutron radiation field in scanning proton therapy. Mares et al. (submitted to Int J Radiat Onc Biol Phys.)
\( H^*(10) = 1.16 \, \mu\text{Sv.Gy}^{-1} \)

\( H^*(10) = 2.67 \, \mu\text{Sv.Gy}^{-1} \)

\( H^*(10) = 0.97 \, \mu\text{Sv.Gy}^{-1} \)
Craniospinal irradiation for medulloblastoma using passively scattered proton beams

Vary with age at exposure, attained age, gender, genetic profile.....

Absorbed dose distribution

Second cancer mortality distribution

Second cancer incidence distribution

Radiotherapy: the complete dose specification

Proton Radiotherapy
- TPS calculations
- Out-of-field dosimetry models
- Phantom & dosimeter development
- Proton & neutron out-of-field dosimetry in anthropomorphic phantoms

Radiotherapy Imaging & IGRT
- Measurement of doses from kV imaging
- Measurement of doses from MV imaging
- CT
- Molecular imaging: SPECT, PET
- Phantom & dosimeter development

Photon Radiotherapy
- TPS calculations
- Out-of-field dosimetry models
- Photon out-of-field dosimetry in anthropomorphic phantoms
- Phantom & dosimeter development

Complete dose specification
Input to epidemiological studies and dose-risk models

Complete dose specification

Input to epidemiological studies

Risks of non-cancer effects
- Cardiovascular disease
  - e.g. pericardial & myocardial disease, valvular defects, coronary artery disease (from breast & Hodgkin’s RT)
- Other organs
  - Digestive, lung, eye, thyroid, liver, kidney, cognitive/neurological effects ...

Second cancer risks
(especially in children and young adults)

Risks to the irradiated foetus

Stochastic and deterministic risk models
Summary

• Radiotherapy: the opportunity to study late effects of human irradiation

• Radiotherapy offers:
  o a very large worldwide patient cohort
  o Planned, controlled and documented irradiation
  o wide range of doses to out-of-field organs from approx. 10 – 1000 mGy

• The complete dose specification must be determined for input to epidemiological studies (i.e. out-of-field organ doses from therapy and concomitant imaging procedures)

• Dosimetry techniques to achieve this should be developed and harmonised within Europe
Acknowledgements:

• Members of, and contributors to, EURADOS Working Group 9

• EURADOS Council

• Invaluable assistance given by many colleagues in the centres where experimental measurements have been carried out

Thank you for your attention