Report on ESTRO 2015

Michele Togno, 25-28 April 2015


3RD ESTRO
FORUM
24 - 28 April 2015
Barcelona, Spain

3rd ESTRO Forum

- Physics Biennial Meeting:
  - Teaching lectures
  - Symposium
  - Proffered papers
- Exhibition
- Poster session
- Other sessions: Clinical, RTT, PREVENT & TARGET, GEC-ISIORT

Robin Garcia
Chair, Scientific Advisory Group for the Physics Biennial Meeting

PHYSICS BIENNIAL MEETING

The Scientific Advisory Group for the Physics Biennial Meeting has compiled an exciting programme which will run in parallel with tracks from other disciplines.

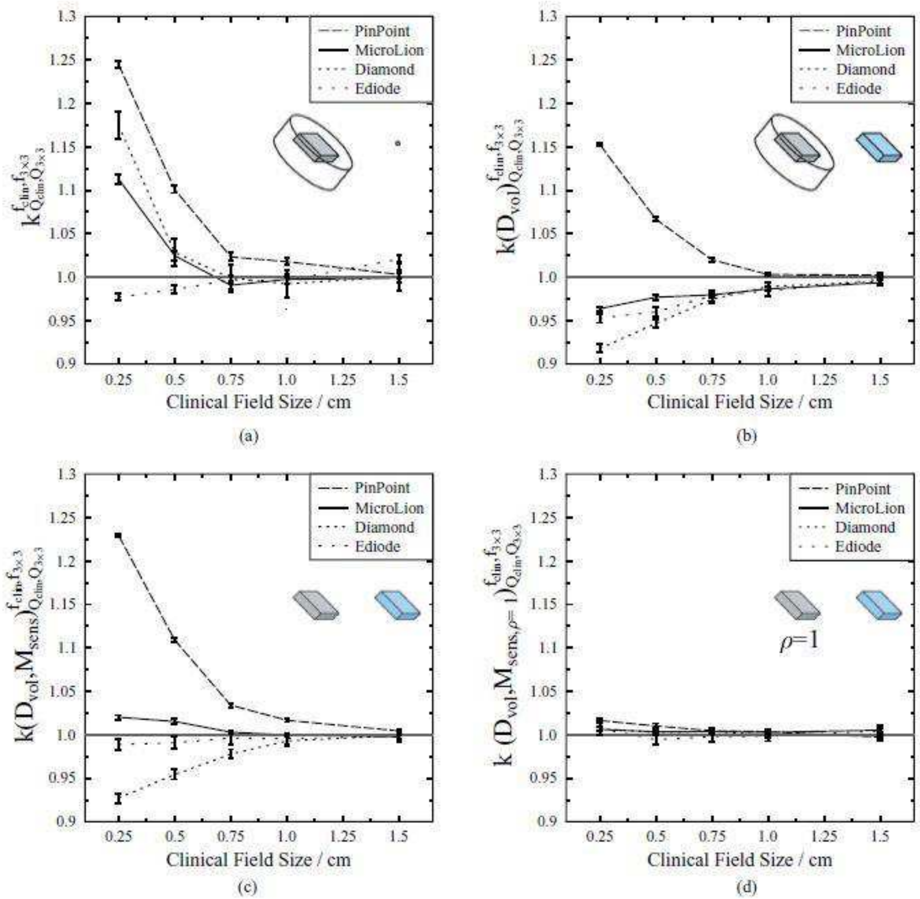
The physics sessions cover a pre-meeting course, eight teaching lectures, 13 symposia, a debate and also some joint sessions with other scientific organisations.

The scientific programme for physicists offers a complete coverage of medical physics domains which we hope will satisfy attendees' expectations. Here are some of the topics covered: MRI, 4D imaging and delivery, functional imaging, low energies to ion beams, nano-dosimetry, small fields, recent detectors, hypo-fractionation and SBRT, side effects, secondary cancer, uncertainties, high technologies, MC, adaptive.

Improving detector response in small photon fields

Monte Carlo study

- Detector response in small fields influenced by: volume-averaging & photon spectra.
- Ideal detector: small, atomic composition close to water -> small ion chambers and diamond detectors (& diodes)
- More recently: LEE breakdown at 1.5 cm for 6 MV. That means the response is substantially influenced by density (0.001 2.3 3.5)
- Liquid ion chambers and plastic scintillators have roughly unit density
- Response influenced not only by density of sensitive volume, but by densities of components as well: it can be improved through density compensation



"Validation of a prototype DiodeAir for small field dosimetry"
Underwood et al., Phys Med Bio 2015 Apr 7;60(7):2939-53

Small field dose measurement

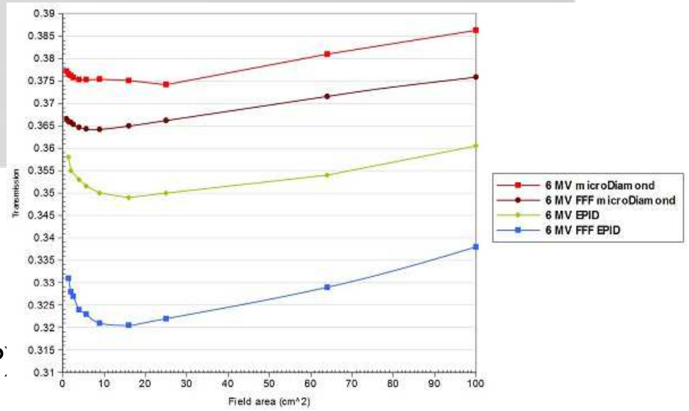
Detectors and correction factors

- **<u>Are correction factors needed for PTW microDiamond detectors in small fields?</u>**
  - Significant overresponse (Lechner 2013, Azangwe 2014) or correction factors are negligible (Chalkley 2014, Das 2014, Morales 2014, Kee 2014, Papaconstadopoulos 2014)?
  - OF meas. (6 MV for Varian, Elekta, Siemens) with cone collimation down to 4 mm and MLC collimation down to 5 mm, compared with fibre optic dosimeter (1 mm plastic scintillator) radiologically water equivalent
  - Outcomes: microDiamond over-responded by up to 9% and 6.5% for a 4mm and 5mm collimated field. Cause: Al electrode and diamond substrate (electrons generated in high density materials)
  - Lack of consensus in literature: no correction for volume averaging, non water equivalent reference dosimeters

Small field dose measurement

Detectors and correction factors

- <u>**Behavior of backprojection EPID dosimetry for small fields**</u>
  - Evaluation of transmission of the dose as a function of field size
  - Deviation from the expected behavior of transmission (spectral changes?)



- <u>**On the accuracy of the Exradin W1 and the spectrum calibration method in scintillation dosimetry for small fields**</u>
  - Negligible corrections to dose measurements, but possible perturbations due to Cerenkov light production in the optical fiber
  - Need for a method to decouple the CRV from scintillation signal
  - Agreement within 1% with expected MC values

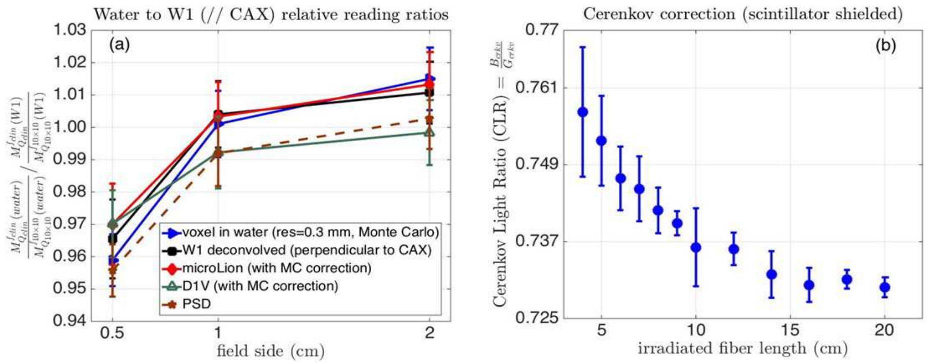


Figure 1: Relative reading ratios of the Exradin W1 to dose in water calculated with 4 independent methods (a) and dependency of the Cerenkov correction to the W1 irradiated fiber length (b)

- **GENERAL COMMENT:** no perfect detectors for OF measurements under 10 mm, effective field size has a great influence! (2% each 0.1 mm)

Planning strategies for SBRT

When delivered dose can be significantly different from the prescribed one

Address three main critical issues:

- Dose reconstruction in heterogeneous media taking into account deformable geometries (ie intrafraction organ motion and adaptive radiotherapy)
- Is there an advantage to introduce non-coplanar beams; and how important is the number of beams?
- Is fast, flattening filter free, volumetric modulated arc therapy the solution to reduce influence of intrafraction motion, or does the interplay effect make it worse?

Outcomes summary:

- FFF beams, high dose rates, dose escalation, hypofractionation, gating & tracking: QA in homogeneous phantom using plane gamma analysis do not seem adequate
- Dose should be calculated on 4D CBCT in the future
- The knowledge of delivered dose might lead to a better understanding of biological effects and to more robust planning

Planning strategies for SBRT

When delivered dose can be significantly different from the prescribed one

- There are already clinical implemented plan optimizer which can generate automatically plans for a specific localization and perform an unbiased comparison of their impact. Non coplanar beams and a high n. of beams can generally increase the quality of the treatment

- SBRT in VMAT technique with FFF beams (up to 2400MU/min) can results in a treatment time of about 2-3min

- Brief intrafraction shifts may lead to larger dosimetric differences than for slower deliveries, as well as the interplay effects can be larger for the faster deliveries

- Margin reduction depends also on the frequency and accuracy of the imaging of course

Recent detectors & dose measurement challenges

MV x-ray beams

- Ideal detector characteristics: repeatability, high sensitivity, tissue equivalence…
- REFERENCE DOSIMETRY: Bragg theory conditions – ion chambers
- RELATIVE DOSIMETRY: Non uniform fluence (energy dependence, volume averaging) – which detector?

  - LARGE FIELDS: low energy scattered photons (PDD, tails)

    - shielded diodes (tissue equivalence)

    - ion chambers (polarity effect, stem effect in scanning measurements, energy dependence of AL or steel electrodes)

    - organic scintillators (good water equivalence, temperature dependence, time to thermal equilibrium, -3% at 25x25cm 6 MV)

  - SMALL FIELDS: small volume, low interaction, low sensitivity, high stem effect

    - diode (tissue equivalence)

    - ion chambers (perturbation from walls, cavity & electrode)

    - synthetic diamonds (over response due to high density)

- **Study on measured kQ values for FF & FFF clinical photon beams**
  - Six reference type ion chambers (Farmer), 6 MV & 10 MV: differences in kQ values are negligible (<0.001)

Recent detectors & dose measurement challenges

MV x-ray beams

- **<u>Dosimetry in an MR-linac beam</u>**
  - 4 different chamber types and alanine dosimeters to determine correction factors and the optimum setup for ion chamber based dosimetry in MR-linacs
  - The chambers used were a PTW Farmer-type chamber (TW30012-1), a PTW waterproof Farmer-type chamber (TW30013), a 2611-type chamber and an Exradin A1SL chamber. Alanine pellets were used in a Farmer-shaped PEEK holder.

Dose measured in MR-linac beam (cGy)					
Chamber type	(using chamber calibration factor)	(using alanine calibration of linac in terms of cGy/MU)	% diff	(using alanine calibration of side-by-side monitor)	% diff
2611	47.757	47.859	-0.2	47.946	-0.4
TW30012-1	49.019	47.859	2.6	48.154	1.9
TW30013	48.471	47.839	[illegible]	47.636	1.7
A1SL	46.862	47.859	-2.1	47.814	-2.0

Recent detectors & dose measurement challenges

MV x-ray beams

- **EPID based sub-arc dose QA of VMAT**
  - To perform a sub-arc pre-treatment dose verification which point out relevant dosimetric errors obscured when performing integral dose QA of VMAT
  - Acquired images are synchronized to Control Points
  - Systematic and temporal perturbations in MLC positioning and amount of MU delivered were introdced in nominal plans in order to assess the sensitivity: 1mm leaf movement and 1MU/CP addition or reduction over 10 CPs were clearly detectable
  - Already applied in clinical routine

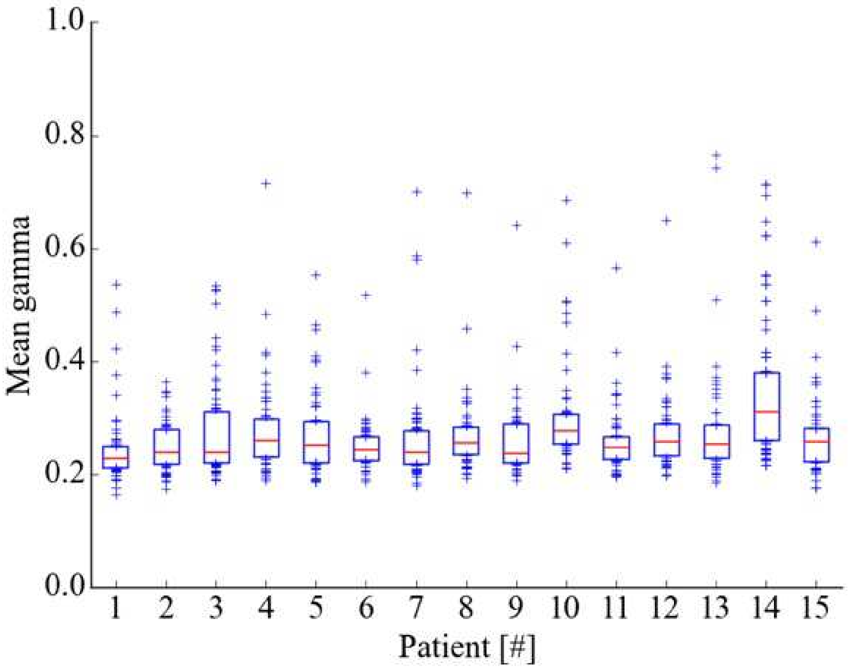


Figure 1 Observed mean gamma values per sub-arc . The box has lines at the lower quartile, median, and upper quartile per patient, the crosses show other values . Averaged over all patients the median mean gamma value is 0.25 ± 0.02.

kV x-ray dosimetry

Address two main critical issues:

- to understand the differences/similarities between dosimetry for these energy range beams when used for therapy or imaging
- to explain MC simulation of kV beams and how to calculate dose to patients from CBCT and kV imaging

Outcomes summary:

- kV x-ray still widely used for skin cancers and relatively shallow lesion.
- there is a growing need for clear recommendations on kV beam dosimetry because of the increasingly wide availability of kV image guidance systems
- Moreover, kV applications in supporting research have included pre-clinical studies using small animal irradiators and microbeam methods
- Knowledge of radiation dose resulting from a kV-CBCT scan and kV radiograph imaging procedures is important for clinicians in making informed decisions for treatment management and risk/benefit analysis.

kV x-ray dosimetry

- The basis of kV dosimetry and the practical methods used are reasonably consistent with MV dosimetry, although uncertainties are typically greater
- All areas of kV beam dosimetry are benefiting greatly from MC modelling, which was proven to provide accurate results for kV dose calculations (performed on patient CT)
- The simulation accuracy was validated by benchmarking the Monte Carlo simulations against measurements of the beam half-value layers and dose distributions
- It is feasible to estimate and account for organ dose by using tabulated values because organ doses from imaging procedures are only modestly dependent upon scan location and body size

Technology edge & New technologies

Interesting and even entertaining debate: have we reached the technology edge in RT?

- We have become 'hostages to commercial fortune' which is a negation of our dignity as scientists and our responsibility as medical practitioners.
- We must stop being in thrall to the techno-geeks - Evolution equipped us with brains, let's use them!
- Today's EBRT is 'North Korean' – instead it should be 'South Korean' i.e. based on enterprise and intelligence

- Improved technology are warranted for safe personalized dose prescription and adapted radiation therapy
- Technology advances can allow for automated procedures in the preparation of treatments, including delineation and planning
- Information technology solutions could automate the follow-up procedures, including evaluation of quality of life, local control, patterns of relapse and survival

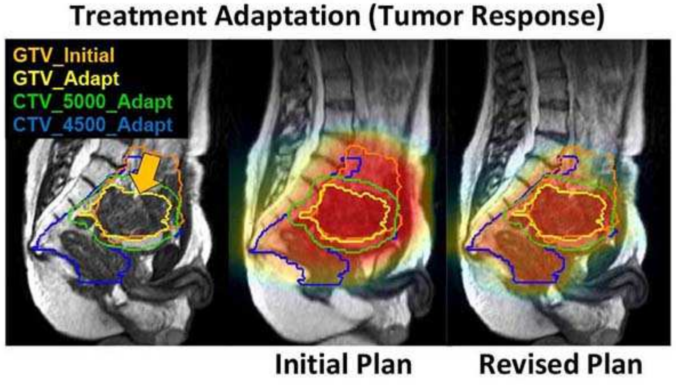
- Whatever is your opinion, you should consider this: in radiotherapy, technology without radiobiology is like driving a Porsche at 40 kilometres per hour

Technology edge & New technologies

New technologies and its clinical implementation:

- **Clinical implementation of online MR-guided adaptive RT for abdominopelvic malignancies (Washing. Univ. Med. Cent.)**

  - MR-IGRT system consists of a split 0.35T MR scanner straddling a ring gantry with three MLC-equipped ^{60}Co heads
  - A high-resolution volumetric MR image is acquired for each patient at the time of daily treatment setup
  - The unit is supported by a fast Monte Carlo based treatment planning system allowing real-time adaptive planning with the patient on the table
  - Five patients with abdominopelvic malignancies have been treated.
  - MR localization images were used to recalculate dose online for all cases. Re-contouring and re-optimization was deemed necessary for 3/5, Reasons for plan adaptation included change in target size, weight loss, and change in small bowel anatomy. The approximate times required for online dose calculation, re-contouring, re-optimization, and QA were 2, 15, and 5 minutes, respectively.



Technology edge & New technologies

- **A unifying system for mechanical and (relative) dosimetry QA in radiation therapy**
  - To replace the multitude of devices with a singular one that measures and records all mechanical, optical and relative dosimetry parameters associated with the monthly quality assurance (QA) of external beam therapy
  - A single 25 cm x 25 cm phosphor screen coupled with an in-line 1.4 mega-pixel CCD camera
  - High spatial resolution for QA at 0.24 mm x 0.24 mm per pixel
  - Several tests: MLC picket fence, isocentricities of collimators, table and gantry, beam energy constancy check.
  - The time spent is reduced by two-third. Most important, the system records and documents optical measurements that are now only evaluated visually which will strengthen the confidence for safe patient treatment.
- **First pulse powered gantry system for laser driven ion beam therapy**
  - Laser-based technology has been established, with protons (upto 20 MeV) via 150 TW laser system (no differences in radiobiological effectiveness)
  - 360° gantry based on pulsed 10 T magnets and novel energy selection system has been designed

Proton Therapy

State of the art

- **An image-guided spot-scanning proton beam therapy gated to real-time tumor-tracking system**
  - 4DRT with real-time tumor-tracking with fiducial markers for small tumors with complex internal organ motion (1999, Hokkaido Uni)
  - New compact system PROBEAT-RT (Hitachi) available since 2014. Possibility to treat large tumor near critical organs with image-guided spot-scanning PT. Real time tumor-tracking: fiducial markers, sets of fluoroscope, gated treatment beam.

- **Dose calculation accuracy in proton therapy**
  - Clinical dose calculations: analytical algorithms vs MC based algorithms
  - Analytical algorithms: pencils structure, computational speed ( ) incorrect modeling of scattering, range uncertainties and dose underestimation ( )
  - Routine MC simulations for treatment planning and verification may be necessary

- **Proton beam monitor chamber calibration in clinical practice**
  - About the application of IAEA TRS-398 dosimetry Code of Pratice to modern proton delivery systems
  - Absorbed dose measurements: calibration with a mono-energetic field or with a SOBP field
  - PP chambers vs cylindrical chambers

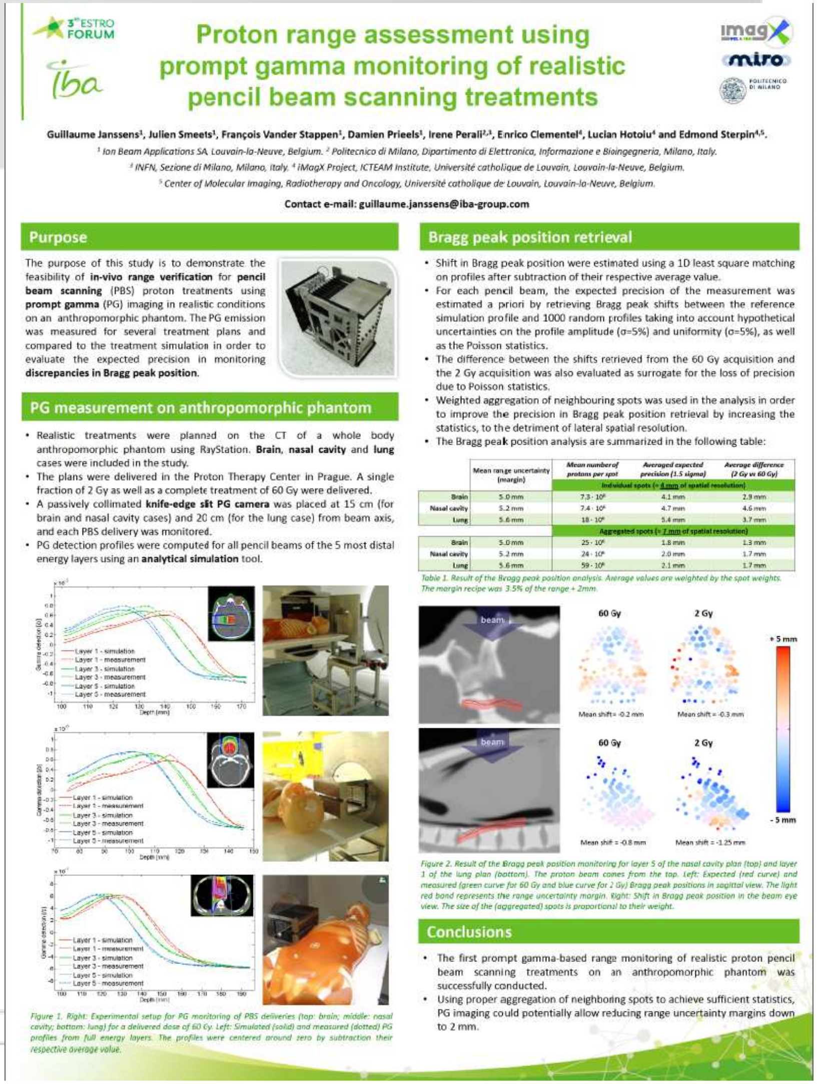
- **Myth and reality of image guidance and adaptive treatments in proton therapy**
  - In the best case, patient anatomy and treatment plans are robust over the entire treatment course. What if not?
  - So far: PTV concept, on line imaging, CBCT, 6DOF treatment couch
  - ON LINE ADAPTIVE PT: library of plans, in-room CT and choose the best day by day. Goal: reduce margins, increase choice in beam direction, find out discrepancies, increase plan robustness

Proton Therapy

IBA PT

You can find it on the web:

http://www.postersessiononline.eu/pr/aula_poster.asp?congreso=61046779



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Proton range assessment using prompt gamma monitoring of realistic pencil beam scanning treatments

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Purpose

The purpose of this study is to demonstrate the feasibility of **in-vivo range verification** for **pencil beam scanning** (PBS) proton treatments using **prompt gamma** (PG) imaging in realistic conditions on an anthropomorphic phantom. The PG emission was measured for several treatment plans and compared to the treatment simulation in order to evaluate the expected precision in monitoring **discrepancies in Bragg peak position.**

PG measurement on anthropomorphic phantom

- Realistic treatments were planned on the CT of a whole body anthropomorphic phantom using RayStation. **Brain**, **nasal cavity** and **lung** cases were included in the study.
- The plans were delivered in the Proton Therapy Center in Prague. A single fraction of 2 Gy as well as a complete treatment of 60 Gy were delivered.
- A passively collimated **knife-edge slit PG camera** was placed at 15 cm (for brain and nasal cavity cases) and 20 cm (for the lung case) from beam axis, and each PBS delivery was monitored.
- PG detection profiles were computed for all pencil beams of the 5 most distal energy layers using an **analytical simulation** tool.

Figure 1. Right: Experimental setup for PG monitoring of PBS deliveries (top: brain; middle: nasal cavity; bottom: lung) for a delivered dose of 60 Gy. Left: Simulated (solid) and measured (dotted) PG profiles from full energy layers. The profiles were centered around zero by subtraction their respective average value.

Bragg peak position retrieval

- Shift in Bragg peak position were estimated using a 1D least square matching on profiles after subtraction of their respective average value.
- For each pencil beam, the expected precision of the measurement was estimated a priori by retrieving Bragg peak shifts between the reference simulation profile and 1000 random profiles taking into account hypothetical uncertainties on the profile amplitude (σ=5%) and uniformity (σ=5%), as well as the Poisson statistics.
- The difference between the shifts retrieved from the 60 Gy acquisition and the 2 Gy acquisition was also evaluated as surrogate for the loss of precision due to Poisson statistics.
- Weighted aggregation of neighbouring spots was used in the analysis in order to improve the precision in Bragg peak position retrieval by increasing the statistics, to the detriment of lateral spatial resolution.
- The Bragg peak position analysis are summarized in the following table:

	Mean range uncertainty (margin)	Mean number of protons per spot	Averaged expected precision (1.5 sigma)	Average difference (2 Gy vs 60 Gy)
		Individual spots (≈ 4 mm of spatial resolution)		
Brain	5.0 mm	$7.3 \cdot 10^6$	4.1 mm	2.9 mm
Nasal cavity	5.2 mm	$7.4 \cdot 10^6$	4.7 mm	4.6 mm
Lung	5.6 mm	$18 \cdot 10^6$	5.4 mm	3.7 mm
		Aggregated spots (≈ 7 mm of spatial resolution)		
Brain	5.0 mm	$25 \cdot 10^6$	1.8 mm	1.3 mm
Nasal cavity	5.2 mm	$24 \cdot 10^6$	2.0 mm	1.7 mm
Lung	5.6 mm	$59 \cdot 10^6$	2.1 mm	1.7 mm

Table 1. Result of the Bragg peak position analysis. Average values are weighted by the spot weights. The margin recipe was 3.5% of the range + 2mm.

Figure 2. Result of the Bragg peak position monitoring for layer 5 of the nasal cavity plan (top) and layer 1 of the lung plan (bottom). The proton beam comes from the top. Left: Expected (red curve) and measured (green curve for 60 Gy and blue curve for 2 Gy) Bragg peak positions in sagittal view. The light red band represents the range uncertainty margin. Right: Shift in Bragg peak position in the beam eye view. The size of the (aggregated) spots is proportional to their weight.

Conclusions

- The first prompt gamma-based range monitoring of realistic proton pencil beam scanning treatments on an anthropomorphic phantom was successfully conducted.
- Using proper aggregation of neighboring spots to achieve sufficient statistics, PG imaging could potentially allow reducing range uncertainty margins down to 2 mm.

Particle Therapy

State of the art

- **The heavier the better: protons vs carbons?**
  - HIT experience with carbon ions
  - Clinical trials started to assess feasibility, toxicity and benefits with respect to protons
  - A long term follow up is needed of course to prove the increase in overall survival fraction
  - Clinical data to support the hypothesis of a better physical dose distribution and biological effectiveness of carbon ions.

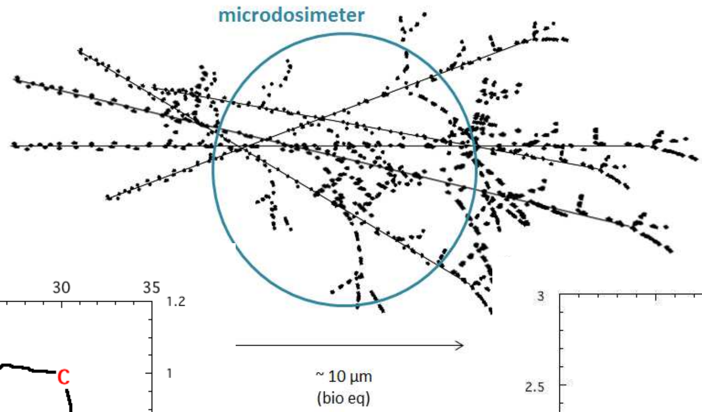
- **Twenty years experience of carbon ion radiotherapy at NIRS-HIMAC**
  - ~9000 patient treated as of 2014 (more than 80% of patients treated worldwide)
  - Experience outcomes: better local control especially fore radio-resistant cancers and locally advanced tumors
  - Treatment course reduced to 1 or 2 fractions for stage I tumors
  - Summary on update status of the delivery system: compact superconducting gantry (minimize time for patient positioning) and spot scanning delivery technique (complex shaped lesions)

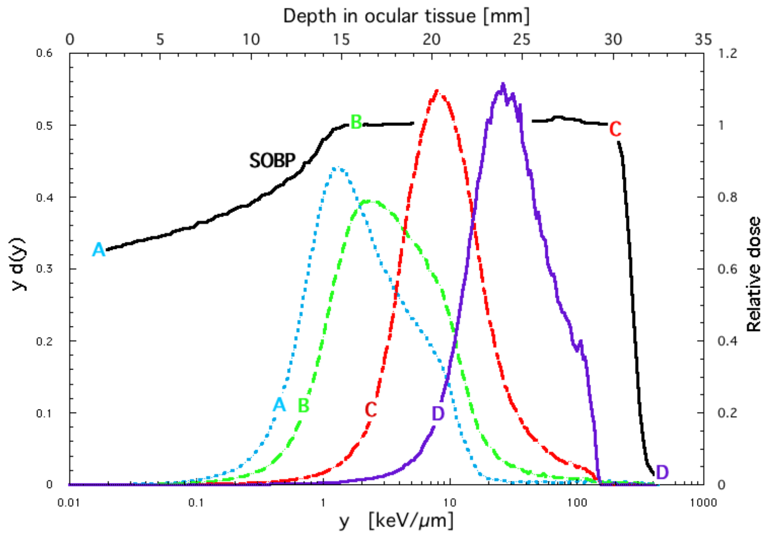
- **The contribution of the ULICE project to the development of hadron therapy in Europe**
  - The aim was to set up a collaboration framework among hadron therapy European centers
  - Establishment of an international board (IONTREB) focusing on clinical aspects of hadron therapy
  - Research activity: novel adaptive treatment planning, reducing dimensions and cost of treatment gantry, radiobiological and physics experiments
  - Networking: beam time for research activities, clinical trials, experience shared with new centers (MedAustron)

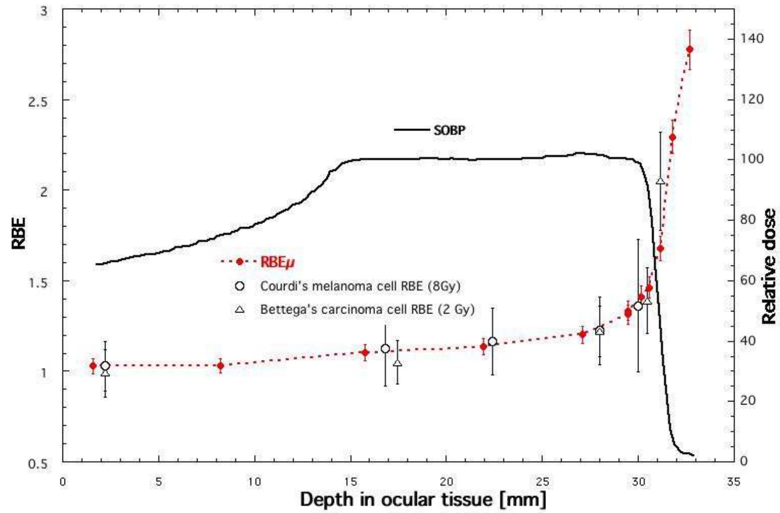
Micro & Nano Dosimetry

The fundamental dosimetry

- **Experimental methods for microdosimetry, nanodosimetry and track structure determination: state of the art**

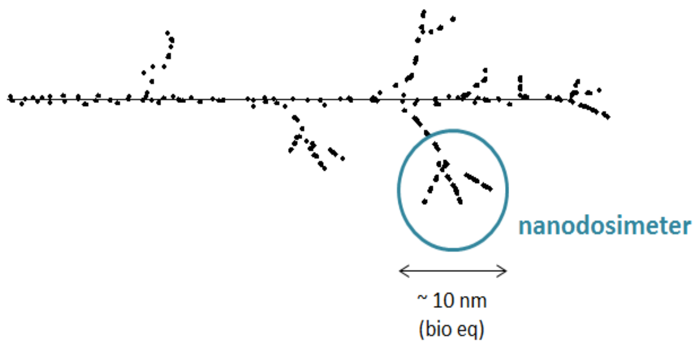


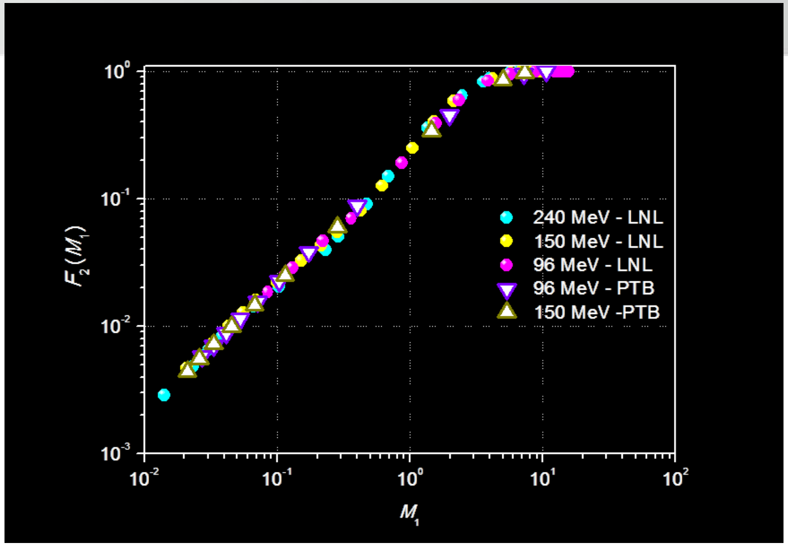




Micro & Nano Dosimetry

The fundamental dosimetry





- **<u>Track structure modelling and biodescriptors of the topology of energy deposition</u>**
  - The approach is to integrate experimental characterization of ion tracks at nanometric level, multi-scale simulation tools and biological effects at cellular level
  - The objective is to derive “biological weighting” functions that could be applied in hadron therapy to experimentally known characteristics of the beam

- **<u>Requirements for multiscale models of radiation action – activities in European projects Nano-IBCT and BioQuaRT</u>**

iRT - IQM

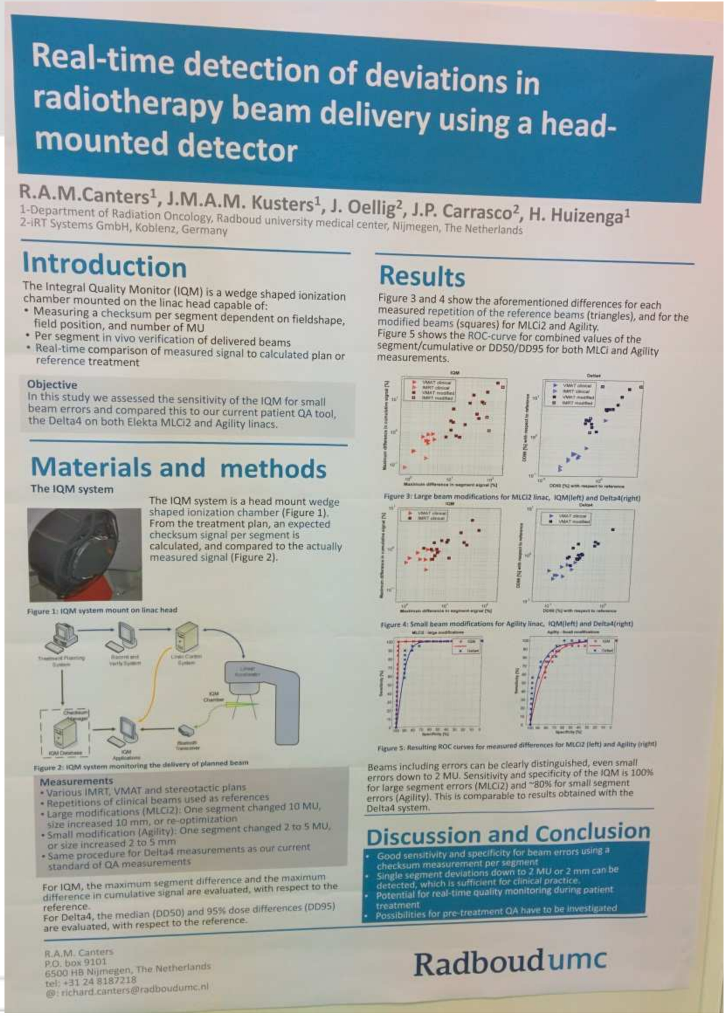
Real time treatment monitor

- Beta-testing presentation (Careggi University Hospital, Florence)
- Meeting with IQM development team

iRT - IQM

The concept in a nutshell

- Single air vented ion chamber, electrode spacing varying linearly along the direction of the MLC motion.
- Checksum value calculated from DicomRT and measured real time segment by segment
- It is intended to be a global treatment monitor, 2MU/2mm detectable change in a single segment
- Intra-fraction and inter-fraction reproducibility better than 0.5% and 1% on the average
- Possibility to use it for pre-treatment QA
- For more info (i.e. measurements of transmission, surface dose, PDD, beam profiles and IMRT verification with both Elekta and Varian linacs): Med. Phys. 2009: “An integral quality monitoring system for real-time verification of intensity modulated radiation therapy”, Islam MK et al.



EPID Dosimetry

Is this the right way?

Real-time EPID based delivery verification during lung stereotactic body radiotherapy: initial experience

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Calvary Mater Newcastle

Centre for Clinical Radiation Research

Initial clinical experience with EPID-based in-vivo dosimetry for VMAT treatment verification

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Fondazione di Ricerca e Cura GIOVANNI PAOLO II

UNIVERSITÀ CATTOLICA del Sacro Cuore

In vivo EPID dosimetry: 3D analysis applied to prostate VMAT treatments

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iba

IBA 1D IC array

Young Scientist Poster Session

You can find it on the network:

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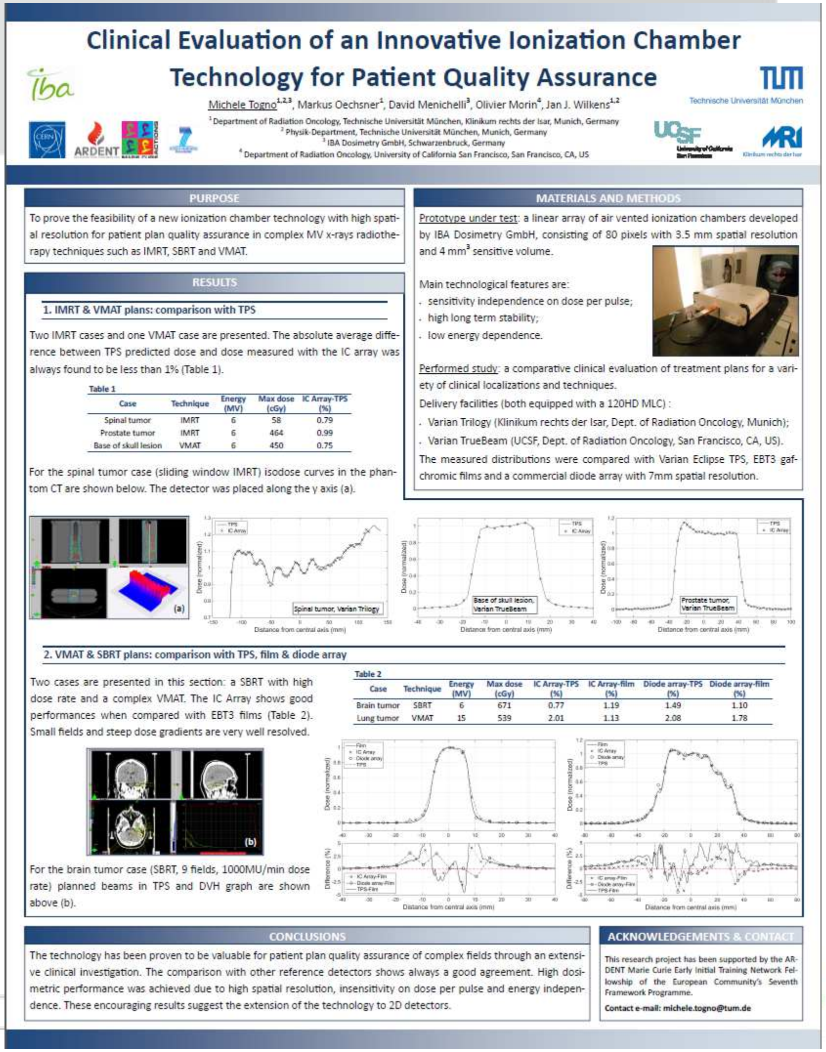

Clinical Evaluation of an Innovative Ionization Chamber Technology for Patient Quality Assurance

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[4] Department of Radiation Oncology, University of California San Francisco, San Francisco, CA, US

PURPOSE

To prove the feasibility of a new ionization chamber technology with high spatial resolution for patient plan quality assurance in complex MV x-rays radiotherapy techniques such as IMRT, SBRT and VMAT.

MATERIALS AND METHODS

Prototype under test: a linear array of air vented ionization chambers developed by IBA Dosimetry GmbH, consisting of 80 pixels with 3.5 mm spatial resolution and 4 mm^3 sensitive volume.

Main technological features are:

- sensitivity independence on dose per pulse;
- high long term stability;
- low energy dependence.

Performed study: a comparative clinical evaluation of treatment plans for a variety of clinical localizations and techniques.

Delivery facilities (both equipped with a 120HD MLC):

- Varian Trilogy (Klinikum rechts der Isar, Dept. of Radiation Oncology, Munich);
- Varian TrueBeam (UCSF, Dept. of Radiation Oncology, San Francisco, CA, US).

The measured distributions were compared with Varian Eclipse TPS, EBT3 gafchromic films and a commercial diode array with 7mm spatial resolution.

RESULTS

1. IMRT & VMAT plans: comparison with TPS

Two IMRT cases and one VMAT case are presented. The absolute average difference between TPS predicted dose and dose measured with the IC array was always found to be less than 1% (Table 1).

Table 1

Case	Technique	Energy (MV)	Max dose (cGy)	IC Array-TPS (%)
Spinal tumor	IMRT	6	58	0.79
Prostate tumor	IMRT	6	464	0.99
Base of skull lesion	VMAT	6	450	0.75

For the spinal tumor case (sliding window IMRT) isodose curves in the phantom CT are shown below. The detector was placed along the y axis (a).

(a) Spinal tumor, Varian Trilogy; Base of skull lesion, Varian TrueBeam; Prostate tumor, Varian TrueBeam — Distance from central axis (mm)

2. VMAT & SBRT plans: comparison with TPS, film & diode array

Two cases are presented in this section: a SBRT with high dose rate and a complex VMAT. The IC Array shows good performances when compared with EBT3 films (Table 2). Small fields and steep dose gradients are very well resolved.

Table 2

Case	Technique	Energy (MV)	Max dose (cGy)	IC Array-TPS (%)	IC Array-film (%)	Diode array-TPS (%)	Diode array-film (%)
Brain tumor	SBRT	6	671	0.77	1.19	1.49	1.10
Lung tumor	VMAT	15	539	2.01	1.13	2.08	1.78

For the brain tumor case (SBRT, 9 fields, 1000MU/min dose rate) planned beams in TPS and DVH graph are shown above (b).

CONCLUSIONS

The technology has been proven to be valuable for patient plan quality assurance of complex fields through an extensive clinical investigation. The comparison with other reference detectors shows always a good agreement. High dosimetric performance was achieved due to high spatial resolution, insensitivity on dose per pulse and energy independence. These encouraging results suggest the extension of the technology to 2D detectors.

ACKNOWLEDGEMENTS & CONTACT

This research project has been supported by the ARDENT Marie Curie Early Initial Training Network Fellowship of the European Community's Seventh Framework Programme.

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PTCOG
54th Annual Conference of the Particle Therapy Co-Operative Group

Thank you