A Look into the Future of External Beam RT: Quality and Science

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Disclosure

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Varian - M. Schweitzer

And the 2011 AAPM Summer School Faculty!

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Radiation Therapy Dose

Can’t smell it, touch it, or feel it – need to place it in the human body to within a few mm and to within a few percent.
We stand on the shoulders of giants - they understood the IMPORTANCE of quality and the intolerance to uncertainty.
Quality is the Priority

RT
Purpose: In 2004, the institution began using four-dimensional computed tomography (4DCT) simulation and then intensity-modulated radiotherapy (IMRT) (4DCT/IMRT) instead of three-dimensional conformal radiotherapy (3DCRT) for the standard treatment of non–small-cell lung cancer (NSCLC). This retrospective study compares disease outcomes and toxicity in patients treated with concomitant chemotherapy and either 4DCT/IMRT or 3DCRT.

Conclusions: Treatment with 4DCT/IMRT was at least as good as that with 3DCRT in terms of the rates of freedom from Loco-regional Progression and Distant Metastasis. There was a significant reduction in toxicity and a significant improvement in Overall Survival.
SBRT Lung: Outcome Trends

Stereotactic Body Radiation Therapy for Inoperable Early Stage Lung Cancer

Robert Timmerman, M.D., Rebecca Paulus, B.S., James Galvin, Ph.D., Jeffrey Michalski, M.D., William Straube, Ph.D., Jeffrey Bradley, M.D., Achilles Fakiris, M.D., Andrea Bezjak, M.D., Gregory Videtic, M.D., David Johnstone, M.D., Jack Fowler, Ph.D., Elizabeth Gore, M.D., and Hak Choy, M.D.

**Design, Setting, and Patients**—Phase 2 North American multicenter study of patients with biopsy-proven peripheral T1-T2, N0, M0 non-small cell tumors less than 5 cm in diameter and medical conditions precluding surgical treatment. The prescription dose was 18 Gy per fraction times 3 fractions (54 Gy total) delivered in 1½-2 weeks. The study opened May 26, 2004, and closed October 13, 2006; data were analyzed through August 31, 2009.

**Main Outcome Measures**—The primary endpoint was primary tumor control with overall survival, disease free survival, adverse events, involved lobe, regional, and disseminated recurrence as secondary endpoints.

**Results**—A total of 59 patients accrued, of which 55 were evaluable (44 T1 and 11 T2 tumors) with a median follow-up of 34.4 months (range, 4.8 to 49.9 months). Only 1 patient had a primary tumor failure; the estimated 3-year primary tumor control rate was **97.6%** (95% confidence interval [CI], 84.3%, 99.7%). Three patients had recurrence within the involved lobe; the 3-year
SD-IGRT: Metastases

CLINICAL INVESTIGATION

PREDICTORS OF LOCAL CONTROL AFTER SINGLE-DOSE STEREOTACTIC IMAGE-GUIDED INTENSITY-MODULATED RADIOTHERAPY FOR EXTRACRANIAL METASTASES

CARLO GRECO, M.D.,* MICHAEL J. ZELEFSKY, M.D.,* MICHAEL LOVELOCK, Ph.D.,† ZVI FUKS, M.D.,* MARGIE HUNT, M.S.,† KENNETH ROSENZWEIG, M.D.,* JOAN ZATCKY, B.S., N.P.,* BALEM KIM, B.A.,* AND YOSHIYA YAMADA, M.D.*

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(all lesions)

(bone only)
Wow, we are good!

- This radiation therapy stuff really works!
- We can relax, maybe we’ve probably been overstating the concerns around uncertainty…
**Hypothesis:** If the rectum is distended on the planning CT, the probability is high that it will be less distended during treatment, and, consequently, the prostate, on average, will be shifted posteriorly during treatment relative to its position at the time of CT simulation.

Methods:

• 127 patients with definitive 3D-CRT for prostate cancer (78 Gy)

• Rectal distension assessed by calculation of the average cross-sectional rectal area (CSA; defined as the rectal volume divided by length) and measuring three rectal diameters on the planning CT.

• Test the impact of rectal distension on biochemical control, 2-year prostate biopsy results, and incidence of Grade 2 or greater late rectal bleeding was assessed.
Results:

Median Cross-sectional Area (CSA) = 11.2 cm²

In Radiation Therapy Oncology Group 9704, as previously published, patients with resected pancreatic adenocarcinoma received continuous infusion 5-FU and concurrent radiotherapy (5FU-RT). 5FU-RT treatment was preceded and followed by randomly assigned chemotherapy, either 5-FU or gemcitabine. This analysis explored whether failure to adhere to specified RT guidelines influenced survival and/or toxicity.
Figure 1. (A) Treatment schema for RTOG Protocol 9704. (B) Consort diagram.
Figure 2. (A) Survival results. Survival results by randomization between treatment arms. There is no significant difference in survival between the two treatment arms. Median survivals: 5FU arm = 1.43 years; gemcitabine arm = 1.55 years (p = 0.51).

(B) Survival results by radiotherapy quality (RTQA) score as per protocol (PP) or <PP. Patients with RTQA score of PP had significantly better survival; 1.74 years vs. 1.46 years (p = 0.0077).
Critical Impact of Radiotherapy Protocol Compliance and Quality in the Treatment of Advanced Head and Neck Cancer: Results From TROG 02.02


To report the impact of radiotherapy quality on outcome in a large international phase III trial evaluating radiotherapy with concurrent cisplatin plus tirapazamine for advanced head and neck cancer.
In the overall context of head and neck cancer treatment in the community, these results strongly reinforce the importance of doing well what we already know. It is sobering to note that the value of good radiotherapy is substantially greater than the incremental gains that have been achieved with new drugs and/or biologics.
Overdose cancer girl dies
Thursday, October 19, 2006

A teenage cancer patient who was given a massive overdose of radiation has died.

Lisa Norris, 16, was given 17 overdoses of radiation therapy during her treatment for a brain tumour at the Beatson Oncology Centre in Glasgow in January.

It was reported she died yesterday at her home in Ayrshire surrounded by her family.

Staff shortage led to radiation error: report
Thu, October 30, 2008

Wrong dosage given to 326 Civic Hospital cancer patients

By DONNA CASEY, Sun Media

Staffing shortages among medical physics personnel at the Ottawa Hospital contributed to a calculation error on a radiation machine affecting 326 patients over a three-year period, according to an independent review.
As Scott Jerome-Parks lay dying, he clung to this wish: that his fatal radiation overdose — which left him deaf, struggling to see, unable to swallow, burned, with his teeth falling out, with ulcers in his mouth and throat, nauseated, in severe pain and finally unable to breathe — be studied and talked about publicly so that others might not have to live his nightmare.

Error rates are very low, but not low enough.
Are we really missing things?

Catching errors with *in vivo* EPID dosimetry


*Department of Radiation Oncology, The Netherlands Cancer Institute—Antoni van Leeuwenhoek Hospital, Plesmanlaan 121, 1066 CX Amsterdam, The Netherlands*

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**Fig. 1.** Schematic overview data flow in our department. Solid lines indicate the route that the treatment plans follow (plan transfer steps are indicated with letters). Dashed lines indicate EPID dosimetry information transfer.

“Since the clinical introduction of the method in January 2005 until August 2009, treatment plans of 4337 patients have been verified. Among these plans, 17 serious errors were detected that led to intervention. Due to their origin, nine of these errors would not have been detected with pretreatment verification.”

*Med. Phys. 37 (6) June 2010*
Wow! Quality Matters!

• It matters for our patients.
• It matters for our field.
• It matters for our science.
• It matters for our future patients.
Quality is the Priority

Growing Technological Complexity

RT
Process tree (map)  I wouldn’t try to read it...will hurt your eyes

You are here.

Saiful Huq - New Paradigms for QM in RT

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S. Huq - Monday
Supervised Robotic Intensity-modulated, Image-guided Radiation Therapy

In a period of 10 years, Radiation Therapy has evolved from employing:

10 Mb to 1000 Mb of Data (100X)

10 to 1000 Digital Treatment Parameters (Robotic Control)

Supervised, Image-guided Operation
Next Up: MR-Guided RT Platforms

MR-Guided RT
Fast imaging, higher CNR, more responsive in delivery.

"Lots of times you can’t really see what you are trying to see" – E. Soisson
Why Pursue MR-guided RT?

• Pros
  – Intrinsic Contrast of Target and Normal Tissue
  – No Significant Toxicities
  – Physiological Measurement Capabilities

• Cons
  – Geometric Distortions/Accuracy
  – Influence on Dose Deposition
    • Electron Return Effect (ERE)
  – Safety/Screening/Repairs
  – Cost
SMALL BORE (28 cm) Linac-MRI

- Arrival of bi-planar MRI: on transit
- Excellent linearity (no distortion)
- Parallel imaging (improved image quality & speed)
- 2 linacs already on site
- Medical Physics Development “from scratch”
- Plans for a Body Human System are developed

Courtesy of G. Fallone, Cross Cancer Institute, Edmonton, Canada
Prototype of the Renaissance™ Device

- Co-registered and gantry mounted
  - Open split solenoid MRI
  - MLC-Based cone beam IMRT unit with axial patient access
  - Multiple sources...

- Imaging during beam-on

- Daily optimization

- Daily recording of delivered dose

Courtesy of J. Dempsey, Viewray Inc.
Image guided Radiotherapy: MRI accelerator combination

Courtesy of J. Lagendijk, Utrecht, Netherlands
UMC Utrecht MRI linac system
6 MV linac and 1.5 T MRI

Prototype MRI accelerator

Dynamic prototype under construction

1.5 T diagnostic MRI quality

No impact of beam on MRI

Fig. 1. Radiotherapy building with the MR and the connected accelerator.
The Princess MRgRT Facility

Under construction: Estimated time to completion: 18 Months
The Princess MRgRT Facility

Specifications:
- MR imaging to RT in <90 seconds
- Diagnostic Performance
- Linac and Brachytherapy operate indep. of MR

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Complex Machinery of Adaptive Radiation Therapy

Temporal Scales of Adaptive Radiation Therapy

Off-line
- Auto-segmentation
- Deformation
- Inverse planning
- Dose accumulation
- Response assessment
- PET/MR/CT

On-line
- MV/kV CT, online planning, dose accumulation, rapid QA, monitoring, deformation, seed detection

Real-time
- kV Fluoro, MR-RT, ultrasound, robotic needles/couches, motion tracking, gating, control, prediction

Information

Intent

Therapeutic Intent
(Prescribed Dose and Constraints)

Image-based Information To Inform Adaptation
(Geometry, Biology)

Adaptive Intervention
(External Beam, Brachytherapy)
Quality is the Priority

Growing Complexity

New Science

Where’s the Evidence?
20 Years of Advancing Radiation Therapy: ‘Testing the 3D Hypothesis’

- Transition from ‘technique-based’ approach to employing the 3D information in the creation of the intervention.
  - Information largely derived from imaging
- Move from ‘patterning’ to ‘deriving’ the RT intervention.
- Data driven process that operates on imaging, dose computation, and population-based knowledge of radiation response.
- Enabling dose escalation without corresponding increases in toxicity.
47 patients were assigned to each treatment arm. Median follow-up was 44·0 months (IQR 30·0–59·7). At 12 months xerostomia side-effects were reported in 73 of 82 alive patients; grade 2 or worse xerostomia at 12 months was significantly lower in the IMRT group than in the conventional radiotherapy group.

At 24 months, no significant differences were seen between randomised groups in non-xerostomia late toxicities, locoregional control, or overall survival.
From the ‘3D Hypothesis’ to the ‘4D Hypothesis’

Fundamentally enabled by minimally-invasive methods of characterizing the disease state in the context of intervention

“Probably every patient needs to be monitored, some will benefit from adaptation.” – K. Langen
Fig. 13 shows a series of pictures demonstrating the regression of a seminoma (a very radio-sensitive tumour). The radiation is applied at a low level while the tumour is large, but as the lesion regresses the smaller area is taken advantage of and larger doses are then applied. In this particular case the tumour was completely removed by accurate intense radiation.
Setting Out to Test the 4D Hypothesis: Many Challenges

• Quantification: Without accuracy and precision, there is nothing.

• Integration: imaging and intervention
  – Spatial and temporal proximity to intervention

• Interpretation: Automated methods of deriving intervention from frequent measurement

• Memory: A system to hold the context of the intervention

• Cost: Methods of managing the cost of measurement and adjustment

• Validation and Feedback: Was it all worth it?
“We are dependent on imaging systems, we will be more dependent on imaging systems in the future.” – J. Balter
Personalized Cancer Medicine

“The right treatment for the right patient at the right time”

• Increased effort in the management of a patient
  – Measurement costs, data handling costs, image analysis costs, complexity costs

• Risk of error by exposing the patient to multiple decisions
  – “Uncertainty Exposure” – Measurement/Model
  – “Error Exposure” – Decision Making
The normalized dose-response gradient

\[ \gamma_n = D \cdot \frac{dP}{dD} \approx D \cdot \frac{\Delta P}{\Delta D} = \frac{\Delta P}{\Delta D / D} \]
HNC – Oropharynx: Two Populations?

- Traditional risk factors for head & neck cancers (HNC) are cigarette smoking, and EtOH consumption
- Epidemiology has changed in recent decades
- HPV-related Disease versus Classical Disease
Dynamics of Disease in the Population

Site Specific Incidence of HNSCC in Radiation Oncology at the PMH

All patients with locally-advanced OPC are offered concurrent chemo-radiation
Separation of Patients by p16 Expression

Shi et al; JCO 27:6213, 2009

"If what I said is extremely clear, then you misunderstood.” – S. Bentzen
More Science to Do: Delineation
Rational Margin Design vs Irrational
PTV Constraint

Acta Oncologica, 2008; 47: 1186-1187

EDITORIAL

Will IGRT live up to its promise?

MARCEL VAN HERK

The Netherlands Cancer Institute/Antoni van Leeuwenhoek Hospital, Amsterdam, the Netherlands
Need new, robust information about the extent of disease.

Need to engage pathology more in target characterization.

94 Radiology October 2004 Daisne et al

One of a few papers that have attempted this problem.
From 3D to BTV: It’s a long road.

“Incremental to the concept of gross, clinical, and planning target volumes (GTV, CTV, and PTV), we propose the concept of “biological target volume” (BTV) and hypothesize that BTV can be derived from biological images and that their use may incrementally improve target delineation and dose delivery.” - Ling et al.

“…one more example…” – F-F. Yin
Populating our Models (Quantec Initiative)

Dosimetric Uncertainties and Normal Tissue Tolerance

Ellen D Yorke
Memorial Sloan-Kettering Cancer Center
New York City

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Quality is the Priority

Growing Complexity

New Science

Where’s the Evidence?
Health care today is characterized by more to know, more to manage, more to watch, more to do, and more people involved in doing it than at any time [...]. Our current methods of organizing and delivering care are unable to meet the expectations of patients and their families because the science and technologies involved in health care—the knowledge, skills, care interventions, devices, and drugs—have advanced more rapidly than our ability to deliver them safely, effectively, and efficiently.

(The Robert Wood Johnson Foundation, 1996)
Dave’s Assertion

1. The lack of quality and efficiency in current medical practice will prevent us from testing the personalized medicine hypothesis.

2. The personalized medicine agenda has been and will be accelerated by medical physics engagement because we contemplate uncertainty.
If you

then

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Physicists and their machines.

• Maybe we just need to expand our definition of the treatment machine...

• Expand it to include the system.
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Herring DF, Compton DMJ: “The degree of precision required in the radiation dose delivered in cancer radiotherapy”

Brit J Radiol 5:1112-1118, 1970*

• Recommends that the dose delivered over the course of treatment be known to within ± 5%.
• Achieving this level of accuracy and precision requires that each step of the treatment process performs at a dosimetric precision much better than 5%.
• This places stiff tolerances on both (i) the precision of the clinical dosimetry and (ii) the geometric precision in delivery and planning.
• To achieve and maintain the desired level of precision, it is recommended that a system of treatment delivery be constructed considering dosimetric and geometric factors.

*41 Years Ago
A story about Instrumentation and Discovery

...cloth merchant in Amsterdam - magnifying glasses mounted on a small stand used by textile merchants, capable of magnifying to a power of 3. Improved lens to 300-500X and exposed the field of micro-biology.

Business, Technology, Discovery Science (in that order)
Could radiotherapy become model another well-known large-scale science project?
What would a such an ‘instrument’ for medical discovery look like?

- Precise
  - Measurement
  - Terminology
- Accurate
- Efficient
- Simple
  - As possible

*Things should be made as simple as possible, but not simpler.*

Albert Einstein
An ‘Optimistic’ Perspective

• Continued advances in technology and development of new knowledge will improve the performance of cancer intervention.
  – It will not necessarily be simple.
  – It will not necessarily be elegant.
  – It may be very complex.
  – It will likely be multi-modal.
  – It will be intolerant to errors.

• It will have to be very well-organized.
An ‘Optimistic’ Perspective

- I think we can build this…
- In fact, if we don’t we will be out of a job…
- BTW, the jobs we currently have could be better done by intelligent systems.
- Wouldn’t you rather do some science?

Why am I optimistic?

Do I have any preliminary data?
The Strengthening of the Quality Agenda

Identify four key issues affecting quality in health care delivery:

(1) the growing complexity of science and technology,
(2) the increase in chronic conditions,
(3) a poorly organized delivery system, and,
(4) constraints on exploiting the revolution in information technology.
QUALITY
THE RACE FOR QUALITY HAS NO FINISH LINE-
SO TECHNICALLY IT'S MORE LIKE A DEATH MARCH.
Driving Quality: The Deming Cycle

Plan

Do

Act

Study

Measurement and study is central to The Deming Cycle

William Edwards Deming (October 14, 1900 – December 20, 1993)

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BOX 1.2  FOUR REVOLUTIONS THAT WILL TRANSFORM HEALTH AND HEALTH SYSTEMS

There are four revolutions currently underway that will transform health and health systems. These are the revolutions in: a) life sciences; b) information and communications technology; c) social justice and equity; and d) systems thinking to transcend complexity.


Italics added for emphasis.
<table>
<thead>
<tr>
<th>System Thinking Approach</th>
<th>Usual Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static thinking</strong></td>
<td>Focusing on particular events</td>
</tr>
<tr>
<td><strong>System-as-effect thinking</strong></td>
<td>Viewing behaviour generated by a system as driven by external forces</td>
</tr>
<tr>
<td><strong>Tree-by-tree thinking</strong></td>
<td>Believing that really knowing something means focusing on the details</td>
</tr>
<tr>
<td><strong>Factors thinking</strong></td>
<td>Listing factors that influence or correlate with some result</td>
</tr>
<tr>
<td><strong>Straight-line thinking</strong></td>
<td>Viewing causality as running in one direction, ignoring (either deliberately or not) the interdependence and interaction between and among the causes</td>
</tr>
<tr>
<td><strong>System-as-cause thinking</strong></td>
<td>Placing responsibility for a behaviour on internal actors who manage the policies and “plumbing” of the system</td>
</tr>
<tr>
<td><strong>Forest thinking</strong></td>
<td>Believing that to know something requires understanding the context of relationships</td>
</tr>
<tr>
<td><strong>Operational thinking</strong></td>
<td>Concentrating on causality and understanding how a behaviour is generated</td>
</tr>
<tr>
<td><strong>Loop thinking</strong></td>
<td>Viewing causality as an on-going process, not a one-time event, with effect feeding back to influence the causes and the causes affecting each other</td>
</tr>
</tbody>
</table>

Modified from Richmond, 2000 (28).
RT Towards ‘Systems Thinking’

• Safety and Quality as Priorities
  – Variance Tracking, Measurement
• Advancing a Nomenclature for RT
  – ICRU 50, 62, 83
• Standardization in Treatment Methods
  – Delineation Standards
• Measuring Outcomes
  – Pay for Performance, Expertise Growth
• Engineering Principles
  – FMEA, Control Charts, Measure and Correct Strategy

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Are Quality and Innovation Competitive?

Fresh Thinking on Innovation and Quality

The idea that innovation must embrace both the blue sky and the practical is neither new nor radical, yet we cling to our fascination with the home run.

It makes sense to manage innovation activities with the same management tools and approaches that are used in other major sectors of the business.

ASQ (American Society for Quality) is the world’s leading authority on quality and sole administrator of the Malcolm Baldridge National Quality Award.

ASQ 2010
Standardization and Innovation: A Paradoxical Association?

Not at all.

- DICOM-RT
- TCP-IP
- The kilogram
- The standardized bolt thread

Henry Maudslay (~1800) - the modern screw-cutting lathe made interchangeable screws a practical commodity.
Innovating with Confidence: A Reaction to IMRT/IGRT Deployment

• To address the freedom enabled by the new technologies, needed to revise the infrastructure to support quality and error elimination activities:
  – Change Management:
    • External Beam Process Committee
  – Investigation:
    • QUINCy
  – Analysis, Synthesis, Reporting:
    • Quality Assurance Monitoring Committee is
  – Sharing/Knowledge Transfer:
    • Program-wide QA Conference
  – Peer-review:
    • Site-specific Rounds
‘External Beam Process Committee’

- Change management system for our External Beam treatment practices.

- …innovation not (seen) as a series of unrelated eureka moments, but rather as a process—a change process that can be managed with familiar change management and quality management methods.

ASQ, 2010
It is getting altogether too complex.

We are at the complexity limit!

We can’t do it, will is not enough.
Re: More Photos From Our Trip

To: Jim Rodriguez

Subject: Re: More Photos From Our Trip

Not bad at all. Let's make a plan to check out Tahoe next month. It's supposed to be amazing!

On Jan 27, 2010, at 9:35 AM, Jim Rodriguez <Jim.Rodriguez@me.com> wrote:

Here are a few of my pictures from our trip to Mammoth lake last week. Not bad for an amateur!

I think I've really improved since the last time we went hiking. My friend Jen came along as well. She's a real pro. You two should plan. I think you'll have a lot of fun together!
Dave’s Theory of Complexity Reciprocity

Apparent Complexity

Complexity

2000 2050
Mr. Watt believed that throttling a steam valve by a human being was not the best way to maintain a constant speed of the steam engine.

The beginning of modern automatic control began, when James Watt in 1788 developed a mechanical device the flyball governor.

The flyball governor maintained the speed of the steam engine automatically by controlling the opening and closing of the steam valve.
Automation is Powerful Stuff

- Enabled by Standards and Nomenclature
  - Reporting/Analysis/Comparison
  - Inter-process Communication
- Rapid rate of deployment after the initial organizational investment
  - Auto-segmentation enables other automation
- Reduction in variation (high precision)
  - Seek to improve accuracy

"If to err is human, how do you explain this mess?"
PHYSICS CONTRIBUTION

AUTOMATED PLANNING OF TANGENTIAL BREAST INTENSITY-MODULATED RADIOTHERAPY USING HEURISTIC OPTIMIZATION

THOMAS G. PUR DIE, PH.D., † ROBERT E. D INN I W ELL, M.D., † DANIEL LETOURNEAU, PH.D., ††
CHRISTINE HILL, B.SC., † AND MICHAEL B. SHARPE, PH.D., ††

*Radiation Medicine Program, Princess Margaret Hospital, University Health Network, Toronto, ON, Canada; and †Department of Radiation Oncology, University of Toronto, Toronto, ON, Canada

Purpose: To present an automated technique for two-field tangential breast intensity-modulated radiotherapy (IMRT) treatment planning.

Method and Materials: A total of 158 planned patients with Stage 0, I, and II breast cancer treated using whole-breast IMRT were retrospectively replanned using automated treatment planning tools. The tools developed are integrated into the existing clinical treatment planning system (Pinnacle3) and are designed to perform the manual volume delineation, beam placement, and IMRT treatment planning steps carried out by the treatment planning radiation therapist. The automated algorithm, using only the radio-opaque markers placed at CT simulation as inputs, optimizes the tangential beam parameters to geometrically minimize the amount of lung and heart treated while covering the whole-breast volume. The IMRT parameters are optimized according to the automatically delineated whole-breast volume.

Results: The mean time to generate a complete treatment plan was 6 min, 50 s ± 1 min 12 s. For the automated plans, 157 of 158 plans (99%) were deemed clinically acceptable, and 135 of 158 plans (87%) were deemed clinically improved or equal to the corresponding clinical plan when reviewed in a randomized, double-blinded study by one experienced breast radiation oncologist. In addition, overall the automated plans were dosimetrically equivalent to the clinical plans when scored for target coverage and lung and heart doses.

Conclusion: We have developed robust and efficient automated tools for fully inverted planned tangential breast IMRT planning that can be readily integrated into clinical practice. The tools produce clinically acceptable plans using only the common anatomic landmarks from the CT simulation process as an input. We anticipate the tools will improve patient access to high-quality IMRT treatment by simplifying the planning process and will reduce the effort and cost of incorporating more advanced planning into clinical practice. © 2011 Elsevier Inc.

Breast cancer, Intensity-modulated radiotherapy, Tangential, Automation.
Automated Contouring: Model-based Segmentation

Princess Margaret Hospital
University Health Network

S. Allaire, V. Pekar et al.
Since June 2009, 1050+ patients planned using automated planning tools.
Objectives of Automated Planning Process

Algorithm has learned to set beam gantry and collimator angles, isocenter etc based on 100s of previously treated patients using marks placed at sim for initialization.

Goal is to spare heart, lung etc and cover whole breast volume using init.

Beam optimization will include post-surgery cavity and wire placed on patient at time of sim (if present).

Advanced options can be used to tweak any of the default settings.
Automated Breast Planning Launcher

Setup
- CT Simulator: V7.4 Generic, 120 kVp
- Machine: SV02

Treatment
- Prescription: 4240 cGy in 16
- Site: Whole Breast, Chestwall
- Mode: Breast Coverage, Lung Sparing

[Buttons: Start Automated Breast Planning, Restore Defaults, Cancel]
Automated Breast Planning Launcher

Start Automated Breast Planning  Restore Defaults  Cancel

Setup
- GT Simulator: V7.4 Generic 120 kVp
- Machine: SV02

Treatment
- Prescription: 4240 cGy in 16
- Site: Whole Breast, Chestwall
- Mode: Breast Coverage, Lung Sparing

Defaults
Push Green Button
Get a Treatment Plan
Automated Breast Planning Launcher

- Beam Energy
- Gantry
- Cavity
- Collimator
- Wire
- Shielding
Automated Breast Planning Launcher

Push
Green Button

Get a Treatment Plan
Automated Breast Planning

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Automated Pinnacle QA Report - Automated Tangential Breast

Patient ID: 30000001
Patient Name: Anon. 6930 (restored),
Plan Name: AutoBreast
Revision: E01.P01.D01
Trial Name: AutoTangentIMPO
Institution: Automated Breast Planning
Published By: purple
Published On: 2009-07-16 15:04:39

General Summary (Flags: 1)

Mean Lung Area: 1.8 cm2 (2.0 cm2) .......... ok
Max Lung Distance: 2.4 cm (2.0 cm) >>>>>> noted
CAVITY Margin: 1.1 cm (1.0 cm) .......... ok
Couch Removed Y: 36.2 cm

Beam Summary (Flags: 0)

<table>
<thead>
<tr>
<th>MU Limit</th>
<th>Weight Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial</td>
<td></td>
</tr>
<tr>
<td>--- CP1 Open 140.0 (139.1) .......... ok 88.6% (75.0%) .......... ok</td>
<td></td>
</tr>
<tr>
<td>--- CP2 14.0 (20.0) .......... ok 8.9% (10.0%) .......... ok</td>
<td></td>
</tr>
<tr>
<td>--- CP3 4.0 (20.0) .......... ok 2.5% (10.0%) .......... ok</td>
<td></td>
</tr>
<tr>
<td>--- Total 150.0</td>
<td></td>
</tr>
<tr>
<td>Lateral</td>
<td></td>
</tr>
<tr>
<td>--- CP1 Open 144.0 (139.1) .......... ok 76.6% (75.0%) .......... ok</td>
<td></td>
</tr>
<tr>
<td>--- CP2 6.5 (20.0) .......... ok 3.5% (10.0%) .......... ok</td>
<td></td>
</tr>
<tr>
<td>--- CP3 7.6 (20.0) .......... ok 4.0% (10.0%) .......... ok</td>
<td></td>
</tr>
<tr>
<td>--- CP4 15.6 (20.0) .......... ok 8.3% (10.0%) .......... ok</td>
<td></td>
</tr>
<tr>
<td>--- CP5 14.3 (20.0) .......... ok 7.6% (10.0%) .......... ok</td>
<td></td>
</tr>
<tr>
<td>--- Total 188.0</td>
<td></td>
</tr>
</tbody>
</table>

Setup Summary

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral TTH from Chestboard: 7.0 cm</td>
</tr>
<tr>
<td>Set Depth at Medial Centre Tattoo: 6.3 cm</td>
</tr>
<tr>
<td>Then Shift: 9.4 cm LEFT</td>
</tr>
<tr>
<td>Ant @ Isocentre Depth: 7.1 cm</td>
</tr>
</tbody>
</table>

Medial (Gantry=304°)(Coll= 6°) Depth: 11.5 cm
Medial Field from Medial Tattoo: --- cm ON

Lateral (Gantry=124°)(Coll=354°) Depth: 8.0 cm
Lateral Field from Lateral Tattoo: 0.2 cm POST
### Dose Summary

**Automated Pinnacle QA Report - Automated Tangential Breast**

<table>
<thead>
<tr>
<th>Volume</th>
<th>Dose</th>
<th>Variation</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>aCTV (510.0 cc)</td>
<td>4480 cGy (105.7%)</td>
<td>(&lt;100%)</td>
<td>ok</td>
</tr>
<tr>
<td>----- Max Dose (2.0 cc)</td>
<td>4484 cGy (105.8%)</td>
<td>(&lt;108%)</td>
<td>ok</td>
</tr>
<tr>
<td>aTreated Volume (1220.5 cc)</td>
<td>4076 cGy (96.1%)</td>
<td>(96.1%)</td>
<td>ok</td>
</tr>
<tr>
<td>----- Max Dose (9.9 cc)</td>
<td>4132 cGy (97.5%)</td>
<td>(&gt;95%)</td>
<td>ok</td>
</tr>
<tr>
<td>modCAVITY (9.9 cc)</td>
<td>3898 cGy (91.9%)</td>
<td>(&gt;95%)</td>
<td>ok</td>
</tr>
<tr>
<td>----- Max Dose (64.9 cc)</td>
<td>3870 cGy (91.3%)</td>
<td>(&gt;90%)</td>
<td>noted</td>
</tr>
<tr>
<td>DEVcavity (64.9 cc)</td>
<td>4106 cGy (96.8%)</td>
<td>(&gt;90%)</td>
<td>ok</td>
</tr>
<tr>
<td>aLTLONGS (1038.5 cc)</td>
<td>3556 cGy (83.9%)</td>
<td>(&gt;90%)</td>
<td>ok</td>
</tr>
<tr>
<td>aHEART (550.5 cc)</td>
<td>1894 cGy (44.7%)</td>
<td>(&gt;50%)</td>
<td>ok</td>
</tr>
</tbody>
</table>

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Page 2 of 2
Automated Breast Plans

Published Plans:

• 1050+ approved plans for treatment
• All plans reviewed in multi-disciplinary weekly QA rounds
• Average time for complete plan and documentation in clinical environment:
  8:55 ± 1:23 minutes with standard 810 boxes
  Now: 4-6 minutes with PCM
• ~97% of tangential treatments planned with automated tools
• Exceptions which will be handled in the future:
  – bolus
  – tattoos placed for breast and supraclav treatment for which tangents only treated
  – lung shielding required i.e. wide tangents to include cavity

Date: June 11, 2009 – now
ADAPTATION

The Bad News is Robots can do your job now. The Good News is We’re now hiring Robot Repair Technicians. The Worse News is We’re working on Robot-Fixing Robots—and we do not anticipate any further Good News.
“Physicists would need to have the machine for 8 hours a day just to do all the tests that the new TG-40 would recommend.” – J. Palta
Time for a ‘QA Spring’ in RT QA

Drivers of Change
- Complexity of RT Systems
- Transparency in QA
- Intolerance to Errors
- Manpower Costs
- Systems Thinking

Enablers of Change
- Detector Technology
- Computerization/IT
- Standardized Terminology
- Systems Thinking

Inferred Dose-Geometry Performance
- Star-shots
- Monthly Dosimetry Audits (RPC etc.)
- Multiple Dosimetry Systems
- Daily Flat./Sym.
- Patient-Specific QC
- Manual Oversight
- Labor Intensive
- IGRT Performance

Current State

Explicit Dose-Geometry Performance
- Integrated, Imageable Dosimetry Systems
- Defined Methodologies for Analysis/Action
- Self-Audits
- Semi-automatic Monitoring
- Inexpensive Measurement
- Dual-purpose Patient-Specific QC

Future State
Lowering the Cost of Measurement

An integral quality monitoring system for real-time verification of intensity modulated radiation therapy

Mohammad K. Islam

Department of Radiation Physics, Radiation Medicine Program, Princess Margaret Hospital, Toronto, Ontario M5G 2M9, Canada; Department of Radiation Oncology, University of Toronto, Toronto, Ontario M5G 2M9, Canada; and Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, Ontario M5S 2Z9, Canada

Fig. 8. Sample results for a step-and-shoot head and neck IMRT field. (a) The figure on the left shows the MLC apertures for each segment and the composited fluence map. (b) The results of IQM calculation, measured values, and corresponding percent differences.
Aligning Practice, QC, and On-going Commissioning

Treatment Process

- Imaging
- Treat
- Plan

QA / Management Process

- Routine QA / Treatment
- Data collection
- Quality database
- Process evaluation

With thanks to Tim Craig
IMRT Process Monitoring

165 high-dose measurements
Head and neck IMRT
Pinnacle 7.6c (Sept – Dec, 2005)

IMRT Verification Measurements

Head & Neck Cancers


- 6.2b – low dose
- 6.2b – high dose
- 7.6c – low dose
- 7.6c – high dose

Aug 2005

Radiation Oncology
UNIVERSITY OF TORONTO
Princess Margaret Hospital
University Health Network
P3 vs 2nd Calculation, By Machine Model

~950 Prostate Cancer Treatments
P3 vs 2nd Calculation, Synergy S Models

~950 Prostate Cancer Treatments

Changes To RTP system

disease-based feedback

“Did I mention commissioning is important?” — J. Siebers
Automated beam model optimization

Daniel Létourneau and Michael B. Sharpe
Radiation Medicine Program, Princess Margaret Hospital, Toronto, Ontario, Canada
and Department of Radiation Oncology, University of Toronto, Toronto, Ontario M5G 2M9, Canada

Amir Owranghi
Radiation Medicine Program, Princess Margaret Hospital, Toronto, Ontario M5G 2M9, Canada

David A. Jaffray
Radiation Medicine Program, Princess Margaret Hospital, Toronto, Ontario M5G 2M9, Canada;
Department of Radiation Oncology, University of Toronto, Toronto, Ontario M5S 2E3, Canada;
and Department of Medical Biophysics, University of Toronto, Toronto, Ontario M5G 2M9, Canada

(Received 23 November 2009; revised 26 January 2010; accepted for publication 8 March 2010 published 22 April 2010)
Fig. 4. The non-conforming fraction of diodes is shown as a function of the beam number for the [(a) and (b)] 25 prostate and [(c) and (d)] paraspinal cases. The measured and calculated dose maps were compared for both the initial and the optimized beam models using the following tolerances: 3\% of dose difference (\(\%\Delta D\)) or 2 mm of distance to agreement (DTA) and an inclusion threshold (\(\%\text{Th}\)) of 10\%.
Need for Integrated Database for System Quality/Safety

- Multiple, fragmented software systems that do not communicate
- No centralized QA database for entire RT department
- No efficient reporting mechanism for compliance and performance assessment

As a result, many clinics rely on in-house and inefficient means to perform QA, collect QC data, analyze and manage QC results.

Daniel Létourneau - PMH
Comprehensive Semi-Automated QA

Semi-Automated QC Tests:

- MLC and Jaw Position
- Isocenter Motion
  - Collimator
  - Gantry
  - Couch
- Collimator and gantry readouts
- IG Accuracy
- Dosimetry
  (Matrix and MV flat panel)
MLC Positioning error (mm): Nominal = 100 mm

Mean error: -0.2 mm

Mean error: +0.3 mm
INNOVATION
If It Can Make Your Job Easier, It Can Probably Make It Irrelevant.
Collaborative Approach

The Quantitative Imaging Network (QIN)

- PAR-11-150; a U01 mechanism issued originally in August 2008, and reissued in March 2011.
  - No set-aside funds and no limit to the number of awards
- Submission dates:
  - February 5, June 5, and October 5
  - Electronic submissions through grants.gov
- Reviewed by Special Emphasis Panel (SEP) from NCI

QIBA

- Mission: Improve the value and practicality of quantitative biomarkers by reducing variability across devices, patients, and time
- Current committees:
  - DCE MRI
  - fMRI
  - FDG-PET
  - Volumetric CT
  - COPD-Asthma
From a Through-Away Society to Learning Organizations

Fig. 2.
“The current (data-loss) paradigm.” Data are effectively lost to the wider scientific community after publication. Capturing key datasets in query-able data repositories would accelerate the discovery of causative factors and increase the accuracy of parameter estimates.
IMRT Quality Assurance Program

- Develop and implement an IMRT Quality Assurance Testing Program for Ontario
  - CCO ➔ CAPCA ➔ RPC (yearly)
  - CCO ➔ External IMRT QA ➔ End to End testing
    - Once a year on a case that represents their IMRT practice
- Our Goal:
  - ICPs will develop their own IMRT QA procedures and policies as part of their ramp up of IMRT capabilities
  - This program will provide external validation, time limited as part of the roll-out of IMRT
IMRT Quality Assurance Program

Numerous centers expressed interest in sharing beam models

After running for a few years, it is reasonable to assume we would have >100 accelerators running the best beam model. Why wouldn’t we?

Needs Assessment

Some Results:

- All 13 Centers agreed to participate
- Centers expressed a strong interest:
  - Independent measurements and analysis of dose delivery (13/13)
  - Help define planning and QA goals (10/13)
  - Assess setup accuracy (11/13)
  - Identifying areas for improvements for planning and machine performance (11/13)
COLLABORATION

When a Motivated Group of People Join Together, They Can Turn Problems Into Opportunities. Especially Drinking Problems.
Proficiency Matters!

• It matters for our patients.
• It matters for our field.
• It matters for our science.
• It matters for our future patients.
• It will determine whether we are able to exploit new technologies.
• It will allow us to engage in the science of advancing medicine.

Efficiency Matters!

Efficiency means not re-inventing the wheel.
Summary

• Technological advances allow greater precision and accuracy in radiation therapy and will allow us to measure what we do.

• While traditional approaches to practice have brought the field a long way, our methods and practices are becoming a burden.

• The promising discoveries in clinical science require a level of organization and efficiency that remains elusive.

• Encouragingly, there is a ground swell of ‘Systems Thinking’ that if properly harnessed can transform these concepts into reality.
Thank You
“Medicine is a science of uncertainty and an art of probability”.

“He who studies medicine without books sails an uncharted sea, but he who studies medicine without patients does not go to sea at all”.

“The best preparation for tomorrow is to do today's work superbly well”.

Sir William Osler (1849-1919)
A Canadian Physician,
The Father of Modern Medicine