The History of Automation in Radiation Oncology

A Non-automated, Inexhaustive Historical Review

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Disclosures

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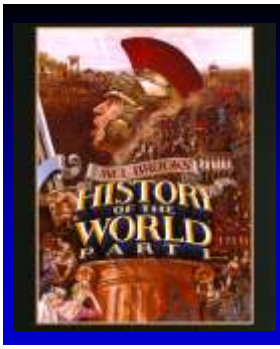
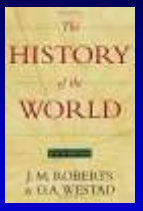
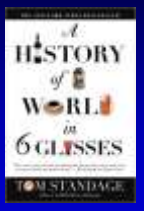
- NIH/NIAID, U19 AI67798 (subcontract 131714)

Useful Precedents…







Automation: *n, def:*

1. the technique of making an apparatus, a process, or a system operate automatically
2. the state of being operated automatically
3. automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labor

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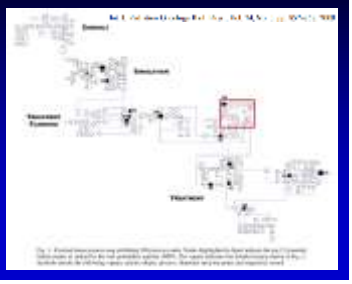
When is Automation of Value or Useful?

- Repetitive processes
- Defined, prescribed, and/or predictable processes
- Processes that can be modeled with fidelity
- Mathematics and logical algorithm implementation
- Hazardous/hostile/remote environments
- Real-time/fast response, complex, large-scale environments
- Personnel time and expense efficiency

The List Goes On… Faster, Cheaper, Better (1 of…all 3)

Automation in Radiation Treatment

- All steps of RT process
  - Consult, simulation, treatment planning, treatment, followup
- Radiation treatment devices
- Quality assurance
- Response assessment

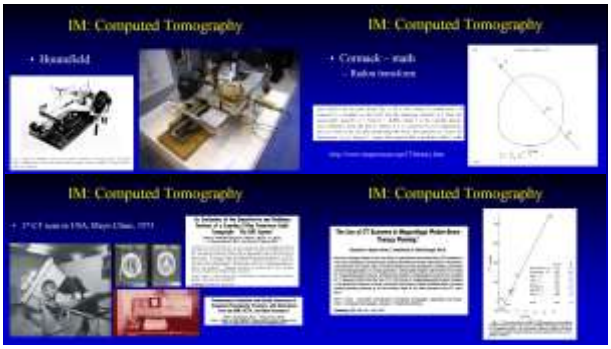


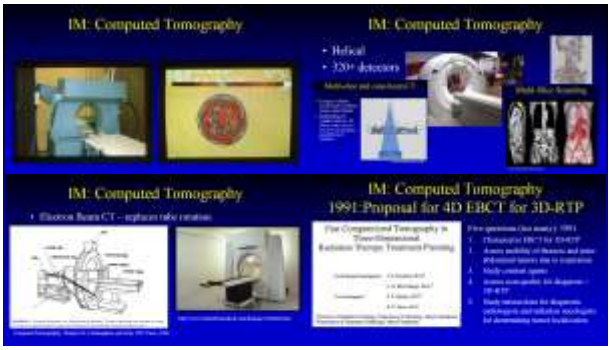
Automation in Medical Imaging

- Computed Tomography
- X-ray Imaging: from film to digital
- Computer-aided Diagnosis (CAD)
- Image processing and manipulation
- Hybrid Devices

IM: Computed Tomography

- Concept – benchtop acquisition, Co-60, Radon transform
- Four+ generations, fan beam
  1. Translate-rotate, pencil beam, single detector
  2. Translate-rotate, fan beam, multiple detectors
  3. Rotate-rotate, fan beam, multiple detectors
  4. Rotate-fixed, fan beam, multiple detectors
- EBT CT – electrical version of mechanical tube rotation
- Multidetector/cone beam CT
- Cone Beam CT – flat pane
- Dual-energy CT; Phase-contrast CT



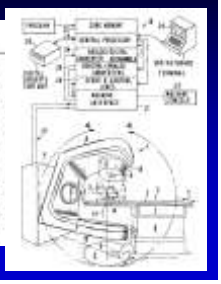


Radiation Treatment: Key Automations

- Linear accelerators
  - Analog → Digital
- CT simulation
  - 4D imaging
- Treatment planning
  - Image segmentation
  - Beam define: MLC, Scanning
  - 3D CRT, IMRT, other
- Immobilization/positioning
- Treatment process
- Motion compensation
- Electronic portal imaging
  - Analog → Digital
- IGRT: CBCT, other modes
- Record / verify
- Database / analysis

RT: Teletherapy, Linear Accelerators

Courtesy Best Medical, Inc.



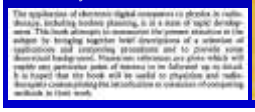
RT: Linear Accelerators

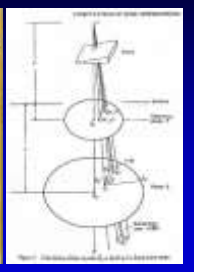
- Digital
- Software Systems
- Automated
- CBCT

Courtesy Varian Medical Systems

RT: Treatment Planning

- Recognized early: 3D/4D
- Tsien KC, BJR 28(332):432-9, 1955. The application of automatic computing machines to radiation treatment planning
- "Beam Superposition" of isodose curves a challenge
- A relatively unheard of book: Woods, 1974
- Real Physics



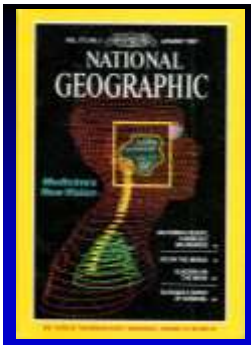


RT: Treatment Planning: 2D → 3D

- 1980s: 2D RTP systems

- 1980s: 3D considered
- Goitein M. Limitations of two-dimensional treatment planning programs. MedPhys 9(4):580-6 (1982)
- The 3D Quest began: MSK, Wisc, UNC, WashU, UWash, UMich

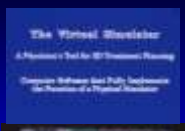
"On The Cover Of The …Rolling Stone"



MSKCC, 1987

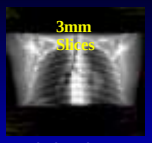
RT: 3D Treatment Planning

~1991

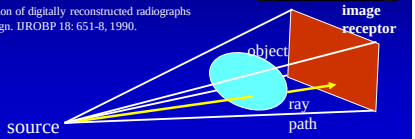


The Digitally Reconstructed Radiograph

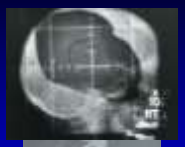
- DRR – a computerized ray trace through a CT 3D digital dataset – a secondary image
- Attenuation properties of material modeled
- Source and image receptor treated as ideal
- Very important step of verification for the virtual simulation process used in 3D radiation treatment planning

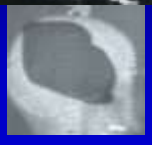


Sherouse, Novins, Chaney Computation of digitally reconstructed radiographs for use in radiotherapy treatment design. IJROBP 18: 651-8, 1990.



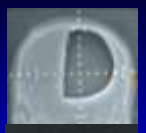
RT: Beam Shaping, 3D CRT

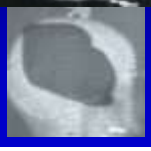




RT: Beam Shaping, 3D CRT

Courtesy AUTIMO Beam Systems



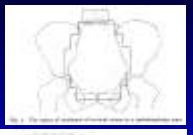


RT: Beam Shaping, 3D CRT - MLC

Courtesy Bourland (Gunderson, Tepper, 2012) and Varian Medical Systems

RT: Conformal Radiation Treatment

- 1959, Tsien
- 1968, earlier, Takahashi



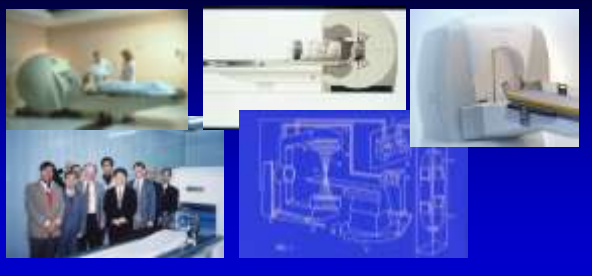
RT: Patient Positioning

"by the numbers"

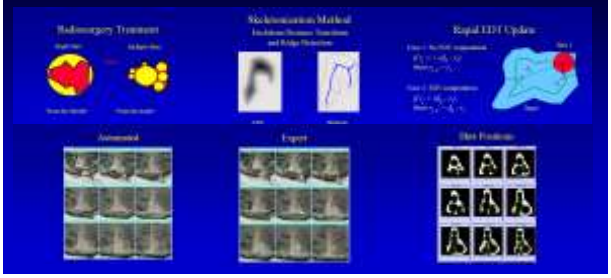
RT: Patient Positioning

Accuracy of a commercial optical 3D surface imaging system for realignment of patients for radiotherapy of the thorax

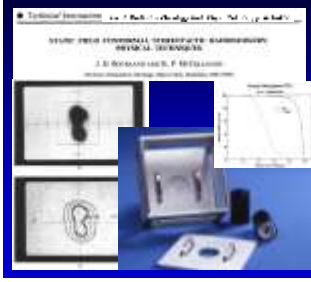
RT: Gamma SRS



RT: Gamma SRS Treatment Planning



RT: Linac SRS Treatment Planning

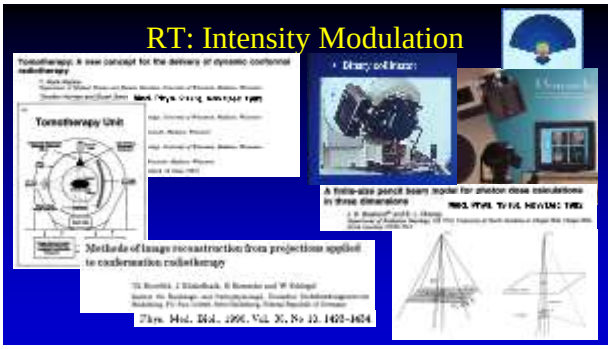


- Shaped fields for linac radiosugery, just waiting for an automated method!
- Mini-MLC

RT: Intensity Modulation

- Use of independent jaws for asymmetric fields leads to dynamic wedge and to further approaches to intensity modulation of the open beam
- The MLC for field shaping can be used for 1) dynamic field shaping as well as 2) intensity modulation
- There are precedents from earlier days: eg, Takahashi

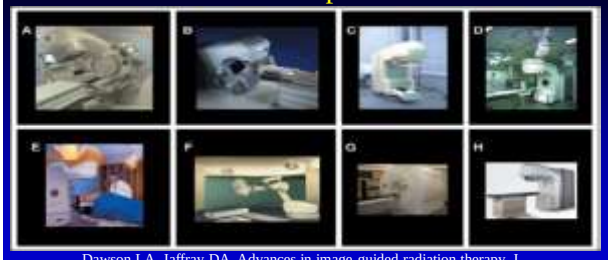
RT: Intensity Modulation



RT: Image Guided Radiation Treatment

1. Optical and Remote Monitoring IGRT, *Sanford L. Meeks, Twyla R. Willoughby, Katja M. Langen, and Patrick A. Kupelian*
2. Ultrasound-Guided Radiation Therapy, *Janelle A. Molloy*
3. In-Room CT System for IGRT, *James R. Wong, Minoru Uematsu, and Zhanrong Gao*
4. Megavoltage Fan-Beam CT IGRT, *Gustavo Hugo Olivera and Thomas Rockwell Mackie*
5. Kilovoltage Cone-Beam CT Guidance of Radiation Therapy, *Jeffrey H. Siewerdsen and Jan-Jakob Sonke*
6. Megavoltage Cone-Beam IGRT, *Olivier Morin and Jean Pouliot*
7. Kilovoltage X-Ray IMRT and IGRT, *Hiroki Shirato, Masayori Ishikawa, Shinichi Shimizu, Gerard, Bengua, Ken Sutherland, Rikiya Onimaru, and Hidefumi Aoyama*
8. Kilovoltage Radiography for Robotic Linac IGRT, *Martin J. Murphy*
9. Respiratory-Correlated CT, *Carnell J. Hampton*
10. 4D PET/CT in Radiotherapy, *Sadek A. Nehmeh and Yusuf E. Erdi*
11. On-Board Digital Tomosynthesis: An Emerging New Technology for IGRT, *Q. Jackie Wu, Devon Godfrey, Lei Ren, Sua Yoo, and Fang-Fang Yin*
12. Image Registration and Segmentation in Radiation Therapy, *Michael B. Sharpe, Michael Velec, and Kristy K. Brock*

Vendor IGRT Implementations



Dawson LA, Jaffray DA. Advances in image-guided radiation therapy. J Clin Oncol. 2007 Mar 10;25(8):938-46.

MR + Linear Acclerator



Longitudinal Orientation

Courtesy of University of Alberta, Canada



Transverse Orientation

Courtesy of University of Alberta, Canada

Hybrid IGRT Technologies: IM + RT

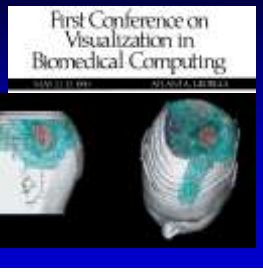
Treatment Device / Modality →

Imaging Device ↓

	Gamma / RadSurg	MV x rays Linac	MV x rays Robotic	Brachy	HiFUS
US		X	?		
Optical		X	X		
Remote Sensing		X	X		
Fiducial Markers		X	X	X	
CT		X		?	
PET-CT		X			
MV FBCT		X			
kV CBCT	X	X		X	
MV CBCT		X			
Stereo XR		X	X	X	
MRI	X	X		X	X
SPECT/NM		X			

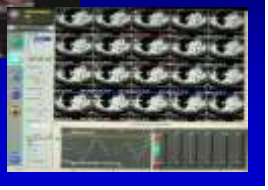
IM + RT: Medical Imaging

- Robb, Pizer, Fuchs …
- Surface rendering
- Volume rendering
- Automated segmentation
- Multi-modality image analysis
- Assessment of treatment response



IM + RT: 4D Imaging

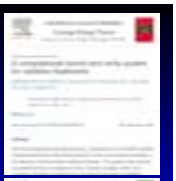
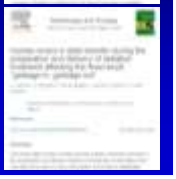


Courtesy, Wake Forest University Baptist Medical Center

RT: Record & Verify: Ha!

- The Trifold Chart – paper system
- Early encoders for patient ID
- Record & Verify – an upload to linac
- Now - R&V is the database that serves the treatment machine
  - Database is King, Information is King!
- BIG DATA – how to analyze?
- We need (to be) "Clinical Informaticists"
- **They may be us, we may be them – We Must Be**

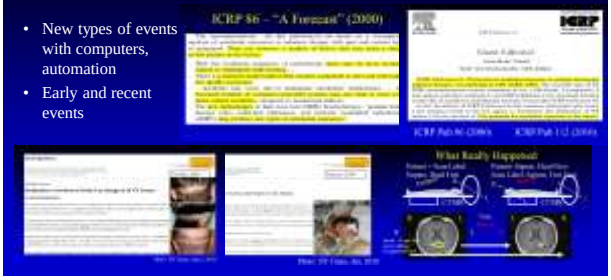



Safety

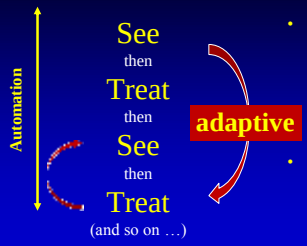
- Everything looks great in the computer…
- We tend to trust technology…
- Automated processes are hidden, may not be revised, customized, corrected…
- We must know how to validate and quality assure for applying to patient care: diagnosis and treatment
- At same time: Automated processes bring control

IM + RT: Safety and Automation

- New types of events with computers, automation
- Early and recent events



The Radiation Targeting Issue



- See
  - How well – target localization?
    - Specificity/sensitivity?
    - Modality?
    - Anatomy, biology?
  - How often?
    - Once, weekly?
    - Per fraction?
- Treat
  - Verification of target hit?
  - Matched to imaging?
    - Static, dynamic, contrast?
  - Readily interpretable?

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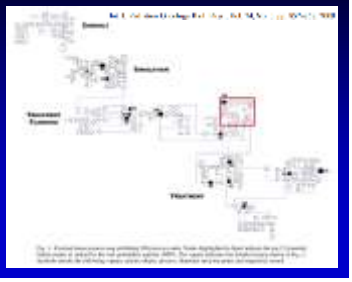

Our Roles in Automation

- Active involvement: must understand and confront problem to propose solution: human + energy source
- W need other perspectives, expertise: non-physicist colleagues
- Recognize the human condition: patient, personnel, public – variable biological response, without perfection – the "3% rule"
- Our contributions: Application of logic, math, technology, expertise, in the clinical setting – it takes all types of us
- Discovery, Integration, Application, Education (Boyer, 1990)

Faster, Cheaper, Better and Safe!

RT: Treatment Planning


Within the next ten years treatment planning will become fully automated without the need for human intervention

Published in 2014, 6 years to go!

Contributions of Automation

- Pre-treatment: Diagnosis, Medical Care Planning
- Radiation Treatment Planning Process
  - Image Segmentation, Radiation "Beam" Design …
- Treatment Delivery Process
  - Positioning / Monitoring, Adaption, Validation …
- Error Detection, Safety Monitoring
  - Real-time / Prospective, Retrospective
- Assessment of Treatment Response: BIG Data
  - Individual/Cohort, Imaging/Treatment Parameters

Contributions of Automation

- Precision Medicine
- Personalized Medicine
- Evidence-based Medicine
- Value-based Medicine

Conclusions on History of Automation

- Automation in radiation oncology (everything) continues
- Useful for repetitive, large-scale, simple and complex, real-time processes: required and invaluable
- May free-up human resources for elsewhere
- Very important roles for automation in safety and evaluation of efficacy and efficiency
- Impact in the clinic, research and education

Responsibility and opportunity await!

A Future with Opportunities

- It really snowed last night! Isn't it wonderful?
- Everything familiar has disappeared. The world looks brand-new!
- … a clean start
- A day full of possibilities
- … a magical world …
- Lets go exploring!