Use of Computers in External Beam Radiotherapy Procedures with High Energy Photons and Electrons

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Advances in Radiotherapy (pre computer era)

Slide from Dr Juliette Thariat
Computer-assisted 1996–2012

Timeline 2: Modern advances in radiotherapy

- **1990s**: Multileaf collimator, driven by computerized treatment planning system, transforms 2D external-beam radiotherapy to 3D conformal radiotherapy
- **1996**: Fluency is optimized with intensity-modulated radiation therapy using multileaf collimators, enabling inverse dose planning and dose-sculpting around concave volumes; sparing the parotids reduces xerostomia after head-and-neck irradiation
- **Late 1990s**: Dose–volume histograms become increasingly used for decision making in 3D conformal radiotherapy planning
- **2000s**: Equipment has been made increasingly accessible to medical practice globally; Particle beam radiotherapy (protons or carbon ions) yields improved tumour coverage and spares normal tissues; Volumated dynamic arctherapy further improves intensity-modulated radiation therapy techniques
- **2005**: Whole-body stereotactic radiotherapy is used for mobile tumour targeting, enabling robotic image-guided technology to track targets in real time
Advancements in Radiation therapy along with computers

- 3D conformal radiotherapy.
- Hounsfield’s invention of CT scans in 1971.
- Use of computers in radiotherapy planning.
- Better radiation dose distributions.
- The introduction of multileaf collimators.
- Computerized algorithms and the new TPS.
- Providing beam-eye-views, rapidly revolutionized radiotherapy.
- Delivery of radiotherapy dose accurately with dose sculpting in 3D onto target volumes and avoiding OAR.
- Cumulative data on clinical tolerance and dose–effect correlations.
- Allowed the definition of specific tolerance doses of OAR using dose–volume histograms.

The need of computers continues to grow in Radiotherapy........
Timeline of Computers in Radiotherapy


Late 1970s—first use was made of CT data for RT planning.

Networking technology became available, computers connected directly together. However, CT scanners still used different file formats.

1980s—first record and verify systems appeared, transmit plans from the planning computer to the record and verify system.

1985, the American College of Radiology and the National Electrical Manufacturers Association created a standard for medical images called ACR-NEMA.

1991, the standard was developed to specify how systems should communicate directly—‘Digital Imaging and Communication in Medicine’, or DICOM 3.0.

1990s—Computer driven of multileaf collimators, electronic portal imaging devices were developed.

At the turn of the millennium, radiotherapy centers were filled with computer systems transferring data—led to the recent development of radiotherapy, or oncology, information systems.
WHAT IS IT ALL ABOUT?

The computer takes analogue data, converts them into digital bits (0 & 1), using software programs to provide speed and precision.
The computer’s role now includes Pervasive Computing and the new bride of the computing world, the Internet of Things (IoT, anything can be connected and communicate in an intelligent fashion).

Modified slide of Victor EKPO, medical physics
Computers help with:

- Speed
- Automation
- Accuracy
Computers in storing Data

The advantages of the computer include its ability to:

• Store large volumes of data.
• Retrieve data within the shortest possible time, with precision.
• Secure (confidential) data, using authentication and authorization.
• Share data faster and easily, to people of interest.
Role of computer in modern Radiotherapy includes but not limited to:

- Database Management
- Radiodiagnosis
- Image Display
- Image Processing
- Digital Radiography
- Computer – Aided Diagnosis
- Imaging Modalities (e.g. CT, MRI, SPECT, PET)
- Radiotherapy
- Computerised Treatment Planning
- Radiotherapy techniques
- Dosimetry
- Follow up and record keeping.
Steps of the treatment planning process, the professionals involved in each step and the QA activities associated with these steps (IAEA TRS 430)

<table>
<thead>
<tr>
<th>People</th>
<th>Process</th>
<th>QA activity</th>
</tr>
</thead>
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<tr>
<td>Radiation therapist</td>
<td>Imaging/contouring</td>
<td>Patient set-up Imaging protocols</td>
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<tr>
<td>Diagnostic radiology</td>
<td></td>
<td>Training of radiation oncologist in GTV, CTV and PTV Use of clinical protocols</td>
</tr>
<tr>
<td>technologist</td>
<td>Target volume and normal tissue definition</td>
<td>TPS commissioning and QA Training of radiation oncologist to use the TPS</td>
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<tr>
<td>Radiation oncologist</td>
<td>Dose calculation/optimization</td>
<td>TPS commissioning and QA Training of treatment planners to use the TPS and MU/time calculation</td>
</tr>
<tr>
<td>Treatment planner</td>
<td>MU/time calculation</td>
<td>TPS commissioning and QA Training of treatment planners to use the TPS and MU/time calculation</td>
</tr>
<tr>
<td>Physicist</td>
<td>First treatment</td>
<td>Process QA Check of set-up parameters</td>
</tr>
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IAEA slide
Understanding the start of computers in Radiotherapy

- In the automatic dose calculation methods described by TSIEN (1955, 1958)-methods were restricted to beams intersecting in one point, and to symmetrical beams.

- Cartesian systems are used-applicable to beams of any shape and asymmetrical beams.

Isodose charts and corresponding field metrics

Isodose diagrams for 80 cm SSD 'OCo, field size 8 x 10 cmz, angles of incidence: 0°.

Field matrices obtained from the isodose diagrams.
Introduction from ICRU 42

• Computer techniques are extensive and diversified.
• To produce a report on treatment planning and recording and documentation procedures in external beam therapy.
• This report will be rapidly outdated; therefore, only the main concepts and basic methods are presented.
Steps in the radiotherapy procedure.

![Diagram showing the steps in radiotherapy procedure](image)
Schematic representation of data flow within a department of radiotherapy.

- Boxes denote the different steps in the radiotherapy procedure.
- The horizontal bars indicate different channels of the logical network.
- A dot means that information exchange occurs with the respective box.
Representation and Modification of Photon Beams

Tabular or matrix format

• The most basic example would be a table of depth-dose data.

• Matrix format—presentation of the distribution of absorbed dose in a plane requires a two dimensional array of numbers.

  ➢ Cartesian coordinates
  ➢ Polar coordinates
  ➢ Fan-line system

• **Beam generating functions/formulas**—such functions are mathematical expressions which facilitate the direct calculation of the relative dose at a point.
Representation and Modification of Photon Beams- Cont

The Separation of Primary and Scattered Radiation.

• Primary radiation - design and construction of the gamma-ray source / x-ray target/ collimation system.
• Scattered radiation - beam size and shape and composition of the volume of material that is irradiated.
Photon Beam Modification

• Beam limiting devices-
  Primary symmetric collimators- already accounted in reference situation.
  Secondary shielding blocks needs to be considered..

• Beam attenuating devices-filters may be interposed in the beam in order to modify the dose distribution-
  flattening filters, wedge filters, compensators.

Beam data acquisition-it is important to provide adequate beam data or each machine and each type of representation
Representation and Modification of High-Energy Electron Beams

• Many similarities between the behavior of electron beams and that of photon beams, there are also many differences.
• Steep fall-off of the depth-dose curve.
• Broadening of the dose distribution with depth resulting in a bulged pattern in the penumbra region,
• Strongly affected by beam limiting and modifying devices.
• Complex behavior of electrons in and around tissue in homogeneities

All of this makes the calculation of dose distributions for electrons more difficult than for photons
Acquisition and Representation of Patient Data

Traditionally, anatomical data represented by a series of transverse parallel sections containing the target volume.

Image acquisition

• Analog methods- external- calipers and lead wires,

For internal topography, orthogonal x-ray films and/or analog images from CT,MRI used in a computer.(care must be taken to avoid distortions).

• Digital Methods- the digital matrices of images may be fed directly into the treatment planning computer for processing and display- contours of internal structures may be generated
Representation of Patient Data-

• Representation of contours in a section.
• Representation of surfaces in a volume: three-dimensional structures are usually acquired and displayed as a series of parallel body sections.
• Representation of densities.
Computation of the Absorbed Dose Distribution in a Patient

- In practice patients are irregularly shaped, heterogeneous in composition, and irradiated in various positions.

- To relate the properties of the radiation beam to the patient it is necessary to set up a coordinate system for each of them and to establish the relationship between the two systems.
Photon Beam Modification by the Patient

- Effect of source-surface distance (SSD).
- Effect of external shape – patients are not cylinders
- Effects of composition and density - patients are inhomogenous
- Volume irradiated - irradiated volume has a complicated shape and differs markedly from the reference situation

Schematic demonstration of the use of outlines (body outline indicated as surrounding an area with electron density, P1 and outline surrounding an inhomogeneity with an electron density, P2) in the calculation of the dose to a point P in the body.
Practical Aspects of Treatment Planning by Computer

- Building a Beam Library.
Input of Patient Data
Practical aspects of treatment planning by computers

• Input of treatment parameters-
  Machine identification, SSD or SAD value, field size, beam direction, etc.).

• Absorbed dose computation time

• Treatment plan visualization and output.
  Interactive presentation- in a computer monitor
  Permanent output- as record in patient file.
Optimization

- Visual interactive and computer optimization procedures can be combined.
- A first choice is made of manually beam directions and field sizes) can be done and a subsequent adjustment is done.
Presentation of Results of Calculation

Information obtained from a treatment planning system consists of various treatment parameters, dose values and dose distributions related to the selected treatment plan.

Alphanumerical
• Identification of patient and dose plan.
• Description of technique.
• Single values of absorbed dose.
• Distribution of absorbed dose.
• Magnitude of areas and/or volumes

Graphic Information
• Identification information to be included.
• Isodose pattern-general remarks.
• Type of presentation-three-dimensional/two dimensional.
Treatment Preparation

- Automatic recording of each session.
- Treatment monitoring (strict criteria's).
- Automatic set-up and dynamic treatment.
- System of documentation must permit a comprehensive description of a given treatment, both during actual treatment and for long-term follow-up.

Fig. 8.1. Example of dynamic treatment of the paraaortic and iliac lymph nodes. The movements of the gantry, couch, and collimator blocks are controlled by a computer. (From Levene et al., 1978.)
Quality Assurance

Introduction of computer technology will improve both the quality of a treatment plan (by permitting more sophisticated plans) and the dosimetric accuracy of the treatments.

• The use of computers will inevitably introduce new risks of error and responsibilities.
• Program and system(computer) documentation.
• Initial system checks.
• Repeated system checks.
• Quality assurance through manual procedures.
• *In Vivo* dosimetry if reqd.
Computers and radiotherapy how they match each other

• In 1965, Gordon Moore, co-founder of the computing giant Intel, predicted that microchip complexity would increase exponentially for at least 10 years.

• In the NHS, a lifetime of 5 years is used for IT equipment, compared to 10 years for a linear accelerator.

• Computer advancements has overtaken Radiation technology in terms of newer developments.

• The results are now seen as an extremely complicated computer network controlling our radiotherapy machines.
Benefits and hazards of computerization

- Modern era of radiotherapy is totally unfeasible without computers or data communication.
- Less chance of human error.
- Computers and networks do fail.
- Systems become more complicated, they are harder to check for errors.
- Computers do not remove the risk of human error altogether
Reverse the assumption that the computer is infallible- Key checks

- Is the isocentre correct?
- Is the reference position correct?
- Has the correct dataset been used for the treatment?
- Now that the treatment can be delivered at the touch of a button, that level of understanding is critical to detect errors.
high-performance computing (HPC) in radiotherapy.

- Real-time requirement of performing three computationally intensive tasks:
  - patient modeling based on deformable image registration.
  - simulation dose calculation using Monte Carlo methods
  - Treatment optimization as a large scale optimization problem.
- A re-planning procedure within 10 seconds, while the current state of the art takes dozens of minutes.
Future of computers in Radiotherapy

Artificial intelligence. Artificial intelligence (AI) is the ability of a computer program or a machine to think and learn. It is also a field of study which tries to make computers "smart". John McCarthy came up with the name "artificial intelligence" in 1955.
People interested in more knowledge
Thank You