ADVANCES IN RADIATION TECHNOLOGIES IN THE TREATMENT OF CANCER

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Based on trends in the incidence of cancer, the International Agency for Research on Cancer (IARC) and WHO have predicted that the number of new cancer cases per year will increase to over 15 million in 2016.

(10 million in 2008)
Incidence/Mortality

International Agency for Research on Cancer
World Health Organization

Both sexes
Numbers, all ages

More developed regions
Less developed regions

Lung
Breast
Colorectum
Prostate
Stomach
Liver
Cervix uteri
Oesophagus
Bladder
Non-Hodgkin lymphoma

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GLOBOCAN 2012 (IARC) (2.5.2016)
Status in Jamaica

- Breast and cervical cancers are the most common cause of death by cancers among females. For males, it is prostate cancer.
Status in Jamaica cont’d

• Cancer is one of the leading causes of death in Jamaica.

• The most commonly occurring of these cancers respond positively to radiation treatment.

• *Radiotherapy* presents an effective and efficient treatment option.
Radiotherapy

The use of radiation for the treatment of cancer and other radiosensitive conditions.
Radiation

Radiation is energy that travels through space or matter in the form of waves or particles.

1. Electromagnetic Radiation
   (e.g. x-rays, gamma rays)
2. Particulate Radiation
   (e.g. electrons, protons, β-particles, etc)
How is the radiation Produced?

Atom - The smallest unit of a chemical substance that can exist by itself.

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How is the radiation Produced?

**X-rays**

In an x-ray machine

*Figure 1.6.* An electron transition filling a vacancy in either the emission of characteristic radiation (A) or the e
Medical Applications

• Diagnostic Radiology
• Nuclear Medicine
• Radiotherapy
  - EBRT
  - Brachytherapy
X-ray Tube & Machines

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3rd Generation Scanner

4th Generation Scanner

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CT Scanning (Sequential)

A rotating beam of x-rays is passed through the patient.

Measurements of the transmitted x-ray beam intensities are made by an array of detectors.

CT images are obtained from these measurements.
Helical/Spiral Scanning
Multi-Row vs Single-Row Detectors

Extremely fast “light speed” when compared with single slice scanner
- completes scan in shorter time >>> cardiac

Thin slices - high resolution - better image detail

Protocols design to optimize detectability in the region of interest.
COMPUTED TOMOGRAPHY

CT Scanner

CT Imaging Process

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CT & Chest X-ray Images

Cross-sectional image  Chest X-ray

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Nuclear Medicine
Nuclear Medicine Hot Lab

Molybdenum Technetium Generator

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PET/CT Imaging
PET/CT Scanner

Advanced nuclear imaging technique that combines Positron Emission Tomography (PET) and Computed Tomography (CT) into one machine.
PET Imaging Principle

Molecules significant for the condition studied, are labelled with a positron emitting isotope such as 18F.

The labelled molecules are then injected into the patient and decay by positron emission.

*Radiopharmaceuticals that can be used for PET imaging include fluorodeoxyglucose (18F-FDG), used to study metabolism, and ammonia (13N), used to study perfusion, … others.*
PET is based on the simultaneous detection of two 511 keV annihilation photons produced when a positron loses its kinetic energy and combines with an electron.
PET/CT
A PET/CT scan reveals information about both the structure and function of cells and tissues in the body during a single imaging session.
Normal PET - CT Body Scan

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Abnormal PET - CT Body Scan
FDG 15 mCi
Bed 1 min
CT (1 min)
KVs 130 kV
mAs 75 mA
Slice 5 mm

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Enhanced Detection
PET/CT in Tumour Imaging

- Detect the presence of cancer in the body - molecular imaging
- Characterise radiographic abnormalities
- Determine the extent of the disease
- Evaluate response to treatment including - chemotherapy from biochemical changes
PET Imaging: Challenge

Major limitation of PET is the cost to establish and operate the required imaging centre with an on-site cyclotron and radiopharmaceutical production facility.
Cyclotron
- particle accelerator

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Radiation Therapy

EBRT
Brachytherapy
Radiation Therapy

• Definition
  The application of ionizing radiation in the treatment of cancer and other radiation sensitive conditions

• Radiation Therapy
  Deliver a precisely measured dose of radiation to a defined cancer volume while minimizing damage to surrounding healthy tissue
External Beam Radiation Therapy in 21st Century

- Several different types of energy used including photons, electrons, and heavy particles (carbon ions, neutrons, and protons) are used today.

- An evolution in the methods to deliver radiation treatment, progressing from 2-DRT to 3DCRT, and more recently, IMRT and others.
How does Radiation Therapy Work?

A Moment of Radiobiology
Determinants of Biological Effects

Radiation source related factors include:

a) radiation quality
b) quantity of radiation exposure
c) dose rate
Conditional Factors

These include:

Linear Energy Transfer (LET)
Dose Rate
Fractionation
Oxygen Enhancement Ratio (OER)
Determinants of Biological Effects

System related factors include:

a) radiosensitivity of tissue

b) complexity of biological system
   - complex systems exhibit more sophisticated repair mechanisms
Interaction of Radiation with Tissue

Direct
DNA, RNA, protein or enzyme becomes ionized by an ionizing particle or photon passing through it.

Indirect
Cytoplasm
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The absorption of radiation by water molecule results in the formation of an ion pair ($H_2O^+$, $H_2O^-$).

$$H_2O + h\nu = H_2O^+ + e^-$$

$$H\_2O + e^- = H_2O^- \text{ (free electron capture)}$$
Interaction with Water Molecule

The ions dissociate to form another ion and free radicals:

$$\text{H}_2\text{O}^+ \rightarrow \text{H}^+ + \text{OH}\cdot$$

$$\text{H}_2\text{O}^- \rightarrow \text{H}\cdot + \text{OH}^-$$

Free Radicals are atomic or molecular species that have an unpaired orbital electron.
Reactions of Free Radicals

Free radicals can combine with other free radicals to form water:

\[\text{H} \cdot + \text{OH} \cdot \rightarrow \text{H}_2\text{O}\]

No biological damage
Free radicals may combine with each other to form hydrogen peroxide which is highly toxic to the cell:

\[
\text{OH}^\bullet + \text{OH}^\bullet \rightarrow \text{H}_2\text{O}_2
\]
Free radicals can act as strong oxidizing or reducing agent by combining directly with intact molecules:

\[ \text{H} \cdot + \text{O}_2 \rightarrow \text{HO}_2 \cdot \]

Oxygen combines with the hydrogen radical to form the highly reactive hydroperoxyl radical.
How does this Happen?

• To treat cancer we need to know exactly where the cancer is located in the body.

• We need to know if it is localised or spread to other parts of the body and where.

• Imaging is required
Treatment Planning (2-D)

Visualize internal organs from any angle to locate and determine tumour volume.

Pinpoints the precise area where the high-energy radiation will be aimed during treatment.

Conventional Simulator University Lodge of the West Indies
Treatment Planning (3-D)

Provides cross-sectional data for 3-D Planning

Virtual simulation for 3-D Conformal Treatment

CT Simulator

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Radiotherapy Treatment

High Energy Treatment Machine used to deliver 3-D Conformal Radiation Therapy.

Superior by far to Cobalt Units used in Public Hospitals

Linear Accelerator (6 MV)

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1. Simulation

2. AP Image

3. 2-D Plan

4. Verification

5. Linac Treatment

2-D Treatment Process

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Radiotherapy Treatment Planning Process (3-D)

1. CT scanning
2. Tumour localisation
3. Skin reference marks
4. Treatment planning
5. Virtual simulation
6. Radiotherapy treatment
- Treatment Position must be accurately reproduced

- Simulator

- Linear Accelerator

- CT Simulator

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- Immobilisation devices
- Indexed fixation points
Treatment Planning (3-D)

Lap Laser system

Lap Computer

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CT Simulation

- Whole Pelvis
- Slice thickness 3mm
- Patient aligned to the fiducials & laser marks
- IV contrast to enhance target & critical organs
- DICOM images transferred thro’ network
CT simulation software

- CT scanner data sent to virtual simulator
- Tumour & sensitive organs outlined on series of axial slices
CT simulation software

- Simulation software calculates geometric centre of tumour volume (∗)

Scan plane: x-y plane

Sagittal MPR: y-z plane

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Medical Physics & Dosimetry

Views with six beams

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Medical Physics & Dosimetry

3-D Rendered with DRR

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Dose Volume Histogram
Medical Physics & Dosimetry

MLC Blades - 120

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Beam’s Eye View
Brachytherapy
Needle, delivering seeds into prostate

Catheter in urethra

Ultrasound probe in rectum for needle guidance

Template to aid accurate placement of the needles delivering the seeds
The ultrasound probe, put on a proper device (stepper), is inserted into the rectum.
Transrectal ultrasound showing a series of prostate ultrasound images used to construct a 3-dimensional image of the prostate (volume study) and treatment plan. Key: Red line = prostate; Blue line = limit of radiation to be delivered.
Study of the distribution of radioactive sources inside the gland and calculation of the radiation dose released to the prostate and surrounding structures (calculation of the isodoses)
Volume Rendered

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Check on the implant quality

Pelvic CT

Pelvic MRI

Even distribution of the seeds in the prostate
Check on the implant quality

3D reconstruction of radioactive source distribution after the implant
Gynecological applicators
High Dose Rate Brachytherapy

- Most modern brachytherapy is delivered using HDR
- Source - Iridium-192
- Reasons?
  - Outpatient procedure
  - Optimization possible
HDR Brachytherapy

• Usually fractionated (e.g. 6 fractions of 6Gy)
• Either patient has new implant each time or stays in hospital for bi-daily treatments
• Time between treatments should be >6 hours to allow normal tissue to repair all damage
Cervical Cancer Treatment

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Other Advanced Technologies
Stereotactic Radiosurgery - Cyberknife

- A form of radiotherapy that focuses a high powered and precise radiation beam on a small area of the body.

- **During treatment:**
- A robotic arm controlled by a computer moves around the patient focusing radiation exactly on the area being treated.
- 1 to 5 Treatment sessions of about 30 min or more depending on dose required.
CyberKnife® - Accuray

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Treatment Applications

- Brain tumours
  - Cancerous and non-cancerous
  - Primary and metastatic – spreading
- Parkinson’s disease
- Epilepsy
Gamma Knife® - Elekta

- Uses 192 to 201 beams of highly focused gamma rays
- Cobalt-60 sources
Xknife - Integra

**XKnife™ by Integra**

- can be adopted to linac
- uses x-rays

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Proton Therapy Machine

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Proton vs Photon

- Relatively low entrance dose (plateau)
- Maximum dose at depth (Bragg peak)
- Rapid distal dose fall-off
- Energy modulation (Spread-out Bragg peak)
- RBE close to unity
Intensity Modulated Radiation Therapy (IMRT)

Multi-leaf Collimator
- typically 120

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Image-Guide Radiotherapy (IGRT) system

- Stereotactic mode
- 6 and 18 MV x-ray beams
  , 6, 9, 12, 15, 18 Mev electrons
- Portal imaging
- Rapid Arc
-- VMAT

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IMRT with DMLC

- Also called as ‘sliding window’
- MLC leaves move when Beam is “ON”

Dynamically moving leaf pair produces desired non-uniform intensity
IMRT for Prostate

- Critical structures sparing like Rectum & Bladder...
- Improved target coverage

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True Dynamic Image Guided
THANK YOU

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