Radiation Protection of Patients in External RT

Impact of New Treatment Technology on Patient Protection in Radiotherapy

Yoshiharu Yonekura MD, PhD
NIRS, Japan
What did we learn from the past?

- **Biological effects of radiation**
  - Threshold for high dose radiation (tissue reaction)
  - Different biological effects among the types of radiation
  - Different response in tumor and normal tissues (dose fractionation)
  - Radio-resistant tumor cells (hypoxia, cancer stem cell, etc.)
  - Individual variation of sensitivity in normal tissues

- **Radiotherapy**
  - Optimize dose fractionation
  - Maximize the target (tumor) to non-target (normal) ratio
Recent Progress in Radiotherapy

- **Improve target /non-target ratio**
  - a. Irradiation from multiple directions (IMRT)
  - b. Ion beam treatment (proton, carbon)
  - c. Brachytherapy (sealed source)
  - d. Molecular target radiotherapy (unsealed source)
Recent Progress in Radiotherapy

- Improve target /non-target ratio
  
a. Irradiation from multiple directions (IMRT)

b. Ion beam treatment (proton, carbon)

c. Brachytherapy (sealed source)

d. Molecular target radiotherapy (unsealed source, BNCT)
Recent Progress in Radiotherapy

- **Improve target / non-target ratio**
  - a. Irradiation from multiple directions (IMRT)
  - b. Ion beam treatment (proton, carbon)
  - c. Brachytherapy (sealed source)
  - d. Molecular target radiotherapy (unsealed source, BNCT)
Recent Progress in Radiotherapy

Challenges in radiobiology

a. Radio-resistant tumor cell
   • Imaging of hypoxic tumor / cancer stem cell
   • Increase dose (dose painting)
   • High LET radiation (carbon-ion)

b. Variation in sensitivity
   • Effects of age / sex; animal experiment
   • Hypersensitive genotype; analysis of clinical sample

c. Integration of physics, chemistry and biology
HIMAC: *Heavy Ion Medical Accelerator in Chiba*

- **Ion Source**
- **Linear Accelerators**
- **Main Accelerator (Synchrotron)**
- **Beam Lines for Physics Research**
- **Treatment Rooms**
- **Room for Biological Experiments**
- **120 x 65 m**
- **300 Million USD**
Milestone of HIMAC Radiotherapy

1984 Carbon ion therapy project started under Comprehensive 10-year Strategic Project for Cancer.

1988 Construction of HIMAC started with vendor partners; Mitsubishi, Hitachi, Sumitomo, Toshiba.

1993 Construction of HIMAC completed.

1994 Clinical trials of carbon ion radiotherapy started.

2003 Approved as advanced medical technology.

2010 Compact system (1/3 in size and cost) in Gunma Univ.

2012 Accept 700 new patients every year, reaching total 7,000 patients.
Need for Multidisciplinary Approach

**Physics**
- Bragg peak
- Distance from Surface (cm)
- Relative Dose (%)
- $\gamma$-ray, neutron, X-ray, proton, carbon
- Tumor

**Biology**
- Survival fraction
- Dose (Gy)
- X-ray, C-ion

**Imaging**
- Hypoxic tumor (resistant to therapy)
- PET ($^{62}$Cu-ATSM)

**Therapy**
- Carbon ion radiotherapy
- Before treatment
- 6 yr after treatment
- Like surgical resection

Cancer stem cells
Characteristics of C-ion Radiotherapy

- **Clinical advantages**
  a. Effective for *intractable tumors* which are *difficult to be resected, and resistant to radiotherapy or chemotherapy*.
     
     Sarcoma, Head & neck (skull-base) tumor, Spinal chordoma, Pancreatic cancer
  
  b. **Short term treatment** is possible with less fractionation.
     
     Lung cancer; 1 day
     Liver cancer; 2 day
     Prostate cancer; 12 fractions / 3 weeks
Characteristics of C-ion Radiotherapy

➤ **Sophisticated procedures**
   a. Maintenance of high energy accelerator
   b. High precision beam delivery
   c. Variable RBE
   d. Treatment planning
   e. Immobilization of patient / respiratory gating

➤ **New problems**
   a. Activation of equipment, air, patient (protection)
   b. Verification of irradiation (dose)
   c. Change of tumor size / shape during treatment (dose)
General Treatment Process

Immobilization → Planning CT → Treatment planning

Beam delivery → Reference Current → Patient positioning
Respiratory Gating Treatment

Lung cancer

Non-gating  Gating
Strategy for Radiological Protection

- Optimize the treatment
  - Provide sufficient dose to the target tumor.
  - Minimize the effects in surrounding normal tissues.

- Safety culture to avoid accidental exposure
  - New methods are associated with complicated procedures.
  - Biological effects appear in the later period.

- Need for long term follow up of the late effects
  - Longer survival of the patients increases the risk of second malignancy.
  - “Low dose” exposure in large area of normal tissues

- Protection of personnel
  - Activation of equipment, air, and patient.
Beam Delivery and Irradiation

a. Broad beam method

- Dose monitor
- Scatterer
- Wobbler magnet
- Compensator
- Collimator
- RSF
- RGF

The beam efficiency is low, about 30%, for the broad beam method. There is a beam loss at every device used to modulate and shape the beam, and those points can be production sources of undesirable radiation such as neutrons.

b. Pencil beam scanning method

- Dose monitor
- RSF
- Scanning magnet

The pencil beam scanning method is characterized by high beam use efficiency, almost 100%, and therefore is low production of neutrons.
Auto-activation PET for Dose Verification

\[ ^{12}\text{C} \rightarrow ^{12}\text{C} \rightarrow ^{11}\text{C} \]

10 min

PET Imaging (30 min)

The OpenPET geometry: original idea to visualize physically open field-of-view

[Yamaya et al, PMB 2008].

In-beam imaging (dose verification)

OpenPET

PET-IGRT (tracking / positioning)

Fragmentation reaction

FDG injection

Real-time imaging. (to be developed)
Carbon-ion RBE of carcinogenesis

Imaoka et al., Int J Radiat Oncol Biol Phys (in press)
How to Apply New Technology for Practice?

- Clinical effectiveness of advanced technology
  - Optimize clinical protocols for diagnosis and treatment
  - Clinical research to establish the evidence
  - Select the most appropriate method for clinical practice

- Safety of new technology
  - Careful and rational design of clinical protocol
  - Based on the basic research in physics and biology
  - Monitoring the process of clinical research
  - Regulation and management of new technology
  - Education / Training for wide clinical use