MEDICAL PHYSICS
CURRENT TRENDS AND FUTURE NEEDS

Sören Mattsson and Diana Adlienè
Medical Radiation Physics, Lund University/Skåne University Hospital Malmö, Sweden and Department of Physics, Kaunas University of Technology, Lithuania
Medical physics is a branch of applied physics.

- Medical physics is in the forefront of the development of medical imaging (X-ray, NM, MR, US).

- Medical physics is pioneering the radiation oncology.

- Medical physics ensure the radiation safety of a large number of patients, occupationally exposed persons and the general public.

- Medical Physics is also very important for the preparedness for severe radiological and nuclear emergencies and disasters.

- Medical physics is now also active in many other fields: optical imaging, nanotechnology, nanomedicine
News:

**New ways of making radiation therapy**

Image guidance, CT → MR, steering the beam from $^{60}$Co and LINACC with MR during treatment

Respiratory modulation

Safety issues.

**Diagnostics**

CT-doses will continue to be a big issue, CT dose reports needed

Screening of lung cancer in high risk patients

New algorithms for reconstruction. How to suck out more of the S/N

Preclinical imaging
Medical physicists have to interface more and better with colleagues, radiologists, oncologists, vendors, administrators

We need to demonstrate scientific excellence, position ourselves, we are real experts, our role should not be limited to do QA/QC, continue to educate ourselves and our peers
In clinical service – try to stay part time active in research
Strengthen the links between clinical work, research and education
Keep imaging physics and radiation therapy physics together

There will be a lot of new equipment.
   We can add values,
   answer questions

We have to take active part in protocol decisions
Lines of development in diagnostics

• New modalities
  – X-ray tomosynthesis (breast, lungs, bone)
  – MR, highfield-MR
  – PET/MR
  – New types of preoperative computed tomography (e.g. O-arm surgical imaging system)
  – US

• New users of advanced X-ray equipment
  – Hybrid rooms (vascular surgery, surgery, orthopedics, maxillofacial surgery)

• New techniques
  – XPCI (X-ray phase contrast imaging; based on measurement of diffraction instead of absorption)
Lines of development for CT

- Large coverage areas (now 160 mm), cone beam
- Rapid collection, 4-5 revolutions/s => 4D
- Multiple kV
- Multiple X-ray tubes and detector arcs
- Iterative reconstruction
  - Photon counting, semiconductors
  - Spectrometry ($\text{PbI}_2$, $\text{HgI}_2$) - CdTe
CT-investigations of children
A number of epidemiological investigations have been initiated. There are results from some: Pearce et al., 2012 and Mathews et al., 2013

The overall conclusion of these two large-scale studies of persons, CT investigated as children, is that the CT-induced risk of cancer was small, but statistically detectable.
<table>
<thead>
<tr>
<th>Period</th>
<th>Main area of development and improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980s</td>
<td>Static magnetic fields</td>
</tr>
<tr>
<td>1990s</td>
<td>Gradients</td>
</tr>
<tr>
<td>2000s</td>
<td>RF-chain, parallel coils, 32,48,64 RF-channels imaging</td>
</tr>
<tr>
<td>2010s</td>
<td>Compressed sensing (reconstruction, undersampling, some applications faster)</td>
</tr>
<tr>
<td>2020s</td>
<td>?</td>
</tr>
</tbody>
</table>

General problem in MR:
Time per investigation: 15 min. – 1 hour

New users of MR-equipment:
- Oncology. Radiation therapy
- Medicine
- Orthopaedics
- (?)
MR
High field (7 T)

Problems:
• Magnet manufacturing
• Helium crisis
Nuclear medicine - Molecular imaging
Imaging

Spatial resolution

CT  MRI  PET  SPECT
US

1 mm  2 mm  4 mm

Sensitivity for detection of contrast media

CT  MRI  PET  SPECT
mmolar  μmolar  nmolar  picomolar
In nuclear medicine/molecular imaging much interest is today directed to:

**PET/CT**

Can measure down to $10^{-11}$ mol/L - $10^{-12}$ mol/L
ABT Molecular Imaging, Inc.
http://abt-mi.com/

**The Accelerator**
- 7.5 MeV Positive ion cyclotron
- 3 internal targets
- Production Rate of 1.0 mCi/min [18F] fluoride
- 1.16 T Magnet
- <5 µA Beam current for F-18 production

**Key features**
- Low power
- Simple one button operation
- Fast Production - dose when needed
- Designed for reliability
- Access to target and ion source for simple replacement
- Turbo Pump vs. oil based diffusion pump

Mini-cyclotron in a 30 m² room for production of \( ^{18}\text{F} \) and \( ^{11}\text{C} \)

Microchemistry system for labeling

(37 MBq/min)
Challenges for medical physicists in radiology

- Development towards a larger part of investigations with equipment that provides potentially higher radiation doses
- Much more complex optimization problems
- Greater need for radiation protection training
- Increased requirements for licensees from radiation safety authorities.

In collaboration with radiologists:
- Train referrals in justification assessment
- Contribute to the use of more differentiated criteria for imaging ("good enough"). Bit of a cultural issue.
- Increasingly, training new (and unexperienced) staff categories
Radiation therapy – an important treatment method for cancer

Radiotherapy saves lives, prolongs lives and improves the quality of lives.

Approximately 50% of all cancer patients receive radiation therapy during their course of illness.

Radiation therapy contributes towards 40% of curative treatment for cancer.
Very high accuracy is needed in radiation therapy.

Radiation therapy is unique among the cancer treatment modalities because it can be modulated in space and in time (4D).
New and better radiation technologies

Conventional treatment technique (forward planning)

IMRT treatment technique (inverse planning) to lower absorbed dose to risk organs
A dramatic technical development

Multi leaf collimator

IMRT

Volumetric arc therapy (VMAT)
Rapid arch
TomoTherapy

Respiratory gating
Volumetric modulated arc radiotherapy (VMAT)
The machine continuously reshapes and changes the intensity of the radiation beam as it moves around the body.
Stereotactic body radiotherapy (SBRT)

- Cancer in the lung
- Cancer in the liver (started there or spread to it)
- Cancers in the lymph nodes
- Spinal cord tumours
Proton therapy

Dose distribution in tissue for protons vs. photons

Absorbed dose in patient vs. Depth in patient (cm)
A **rotating gantry assembly** with three Cobalt-60 teletherapy heads and three multileaf collimators.

A **split-magnet MRI system** for volumetric and multiplanar soft-tissue imaging.

A **patient couch**, two in-room couch control panels, and a laser positioning system to facilitate initial patient setup.

A **control console**, located just outside the treatment room, to start and stop treatment and monitor status.

A **operator console** for MRI acquisition, patient positioning, dose prediction and reoptimization, and real-time tumor tracking.

**Integrated treatment planning and delivery software** for creating treatment plans and managing the treatment delivery process.

A **planning station** for defining structures and constraints and planning and optimizing treatments. Plan review may be conducted remotely.

A **database server** containing patient and machine data used by the system.
Institute for Image Guided Oncological Interventions at the UMC Utrecht
MD Anderson Cancer Center, Houston, Texas, USA
Problems and challenges for medical physicists in radiation therapy

- New challenges: Increased complexity
- Computers everywhere. Software safety, still a subject needing much work
- Non-standard fields, small fields and composite of small field (beamlets), no charged-particle equilibrium. Ex: Gamma-knife, linac with small applicators, IMRT, tomotherapy
- *In-vivo* dosimetry, where, when, how far and how often
- *In-vivo* dosimetry using electronic portal imaging device (EPID)
- Pretreatment verification for IMRT
- More time devoted to treatment planning and pretreatment verification
Problems and challenges for medical physicists in radiation therapy (continued)

- Need for better imaging for dose planning and follow-up
- MRI for better tumour outlining
- MRI for better follow-up
**Radiation technologies**

**Imaging**

**Tumor biology**

- Enhancing conformity
- Anatomy
- Functional & biol inform (metabolism, proliferation, hypoxia, angiogenesis)

- Genomics
- Proteomics
- Metabolomics

**Theragnostics** - the integration of radiation technologies, imaging and biology in radiation oncology
Radiation protection is an essential part of medical physics

- Patient exposure
- Occupational exposure
- Exposure of the public
- Exposure of other organisms than man
- Emergency situations
  - Nuclear weapons
  - Nuclear industries: accidents, attack, sabotage
  - Radioactive substances: theft, intentional distribution
<table>
<thead>
<tr>
<th>Diagnostic imaging</th>
<th>Today</th>
<th>In the future</th>
<th>Problems</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X-ray Nucl med MR Ultrasound</td>
<td>More CT, US, PET/CT, SPECT/CT 7T, MRS 3D real time imaging PET/MR</td>
<td>DRL High CT and PET patient doses X-ray guided interventions Pregnancy Paediatrics Inexperienced users Increasing complexity</td>
<td>Justification of investigations Optimisation Education, training National data bases New imaging technologies</td>
</tr>
<tr>
<td>Radiation therapy</td>
<td>Photons electrons IMRT IGRT</td>
<td>Protons IMPT MR guided RT Heavy ions</td>
<td>Increasing complexity Accidents</td>
<td>Safety culture Indiv RT PET and MR for RT dose planning MR for real time imaging, treatment follow-up Imaging of hypoxia Protons, heavy ions, ...</td>
</tr>
<tr>
<td>Radiation protection patients</td>
<td>CT Intervent Accidents Existing cont areas</td>
<td>Interv outside radiol dept Accidents, terrorists</td>
<td>Skin doses, E (interv X-ray, PET) Fingers and eye-lens Triage, sensitive, fast methods</td>
<td>Education and training</td>
</tr>
<tr>
<td>staff general public</td>
<td></td>
<td></td>
<td></td>
<td>Retrospective dosimetry Dose reconstruction Education, training. Risk communication</td>
</tr>
</tbody>
</table>
... thank you for listening