Radiotherapy technology development and cancer outcomes: past, present and future

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Develop comprehensive motion management solutions for today’s technology

**4D CT imaging**
- 2nd generation 4D CT
- CT ventilation imaging
- Audiovisual biofeedback

**Treatment planning**
- 4D planning for DMLC tracking

**Treatment delivery**
- Resp. motion guided 4D CBCT
- Real-time position estimation
- DMLC tracking

Create tomorrow’s technology

**MRI-linac**

**Nano-X:** Cost effective linac

**Plasma proton accelerator**

**PET-guided linac**
Rationale

New radiotherapy technology
- Audiovisual biofeedback
- Respiratory motion guided 4D cone beam CT
- Real-time tumour localisation and beam adaptation
- Compact linear accelerator
- MRI-Linear accelerator

Summary
TECHNOLOGY TRENDS IN CANCER RADIOTHERAPY
› 114,000 patients diagnosed each year in Australia
   (Cancer Council Australia)
› 46,000 (40%) treated with radiotherapy (Baume 2002)
› Evidence suggests 54,000 (52%) would benefit from radiotherapy (Delaney 2005)
› All* tumours change during and between treatments
› Trend toward increasing application of technology
› Evidence of clinical benefit of better technology
IMAGE-GUIDED RADIOTHERAPY (IGRT) GROWTH (US)

Simpson et al. Cancer 2010
SPECIFIC EXAMPLES OF INNOVATION AFFECTING OUTCOMES
CT simulation

› 15,000 Stage III NSCLC patient SEER database review

› CT simulation rate 2% in 1994 to 78% in 2005

› **CT simulation was associated with lower risk of death** (adjusted hazard ratio, 0.77; 95% CI, 0.73-0.82; P<0.01) compared with conventional simulation.

Chen JCO 2011
4D CT and IMRT

- 496 patient stage I-III non-small cell lung cancer study
- **65% survival increase.** Overall survival (median 1.4 vs. 0.85 yrs, p=0.04).
- **72% toxicity reduction.** Grade $\geq$3 pneumonitis decreased (7% vs. 25% at one year, p=0.02)

Liao IJROBP 2010
NEW RADIOTHERAPY TECHNOLOGY:
Audiovisual biofeedback
Normal breathing is irregular
Irregular breathing causes 4D CT artefacts (>4mm in 90% of scans)
Artifacts mean errors in tumor size, shape and position or missed tumor
Improvements needed!

Yamamoto et al. IJROBP 2008
AUDIOVISUAL BIOFEEDBACK HARDWARE

4D PET-CT imaging

IGRT treatment
STEP 1: LEARN REPRESENTATIVE CYCLE
STEP 2: TRAIN PATIENT

Inhale Limit

Exhale Limit
Free breathing

Audiovisual biofeedback
INTERNAL MOTION WITH/WITHOUT AUDIOVISUAL BIOFEEDBACK

free breathing

audiovisual biofeedback
NEW RADIOTHERAPY TECHNOLOGY:
Respiratory motion-guided 4D cone beam beam CT
CONE BEAM CT IMAGING
THE PROBLEM WITH CURRENT TECHNOLOGY

Current method

› No feedback from patient to acquisition
› Results in bunched projections
› Results in images with artifacts

Proposed method

› Use patient respiratory signal to guide acquisition
› Improve angular spacing of images
› Improve image quality/time/dose
RESPIRATORY MOTION GUIDED 4D CONE BEAM CT

Current 4D CBCT

1. Respiratory signal
2. CBCT projection images
3. Create 4D CBCT imageset

Proposed 4D CBCT

1. Respiratory signal
2. CBCT projection images
3. Is respiratory signal regular?
4. Compute new gantry trajectory
5. Create RM 4D CBCT imageset

Kilovoltage CBCT source

Send new gantry position
Send beam on/pause
IN-SILICO PROTOTYPE

Current method

Proposed method

![Current Method Graphs]

![Proposed Method Graphs]
NEW RADIOTHERAPY TECHNOLOGY:
Real-time tumour localisation and beam adaptation
Typical workflow images prior to and not during tx

X-ray imager (&MV/optical) can add guidance information

(a) kV imager positions

(b) Single-imager tracking

- Segment marker in current kV image
- Estimate PDF using all kV images up to now
- Estimate 3D target position using PDF and current kV image

Poulsen PMB & IJROBP 2008, 2009, 2010
REAL-TIME TUMOUR MONITORING: RESULTS

Poulsen PMB & IJROBP 2008, 2009, 2010
Sub-mm accuracy in prostate; sub 2-mm accuracy in lung

Used in Århus for liver SBRT pre-tx alignment

Observational study competed at RNSH: gated prostate study planned for RNSH
REAL-TIME ADAPTATION: RATIONALE

› All* tumours move during tx
› Many position monitoring systems available
› Multileaf collimator is available
› Why not use to align beam with tumour?
› Porcine model
› MV guidance of stent
› ~370ms latency, corrected after 20s
NEW RADIOTHERAPY TECHNOLOGY:
Compact linac
CURRENT SERVICE GAP IN THE PROVISION OF RADIOTHERAPY

• Optimal utilisation rate for radiotherapy is 52.3%
  Delaney Cancer 2005

• Australia’s actual utilisation rate is 38%
  Morgan J Med. Imag Rad On 2009

• Developed countries is 20-55%
  Delaney Cancer 2005

• Developing countries 0-25%
  Barton Lancet Oncol 2006
CURRENT SERVICE GAP IN THE PROVISION OF RADIOThERAPY

• Shortfall of 5000 RT machines in the developing world

• “Most low and middle income countries simply can’t afford the complex radiotherapy equipment that’s currently on the market and costs over four million dollars” PACT Director Massoud Samiei

• There is a need of reducing the costs of RT machines but not compromising on technology
Number of people served by each radiotherapy centre by country (IAEA)
COMPARISON OF BUNKERS

Nano-X

Conventional compact

primary beam

scattered beam primary beam
## COMPARISON OF BUNKERS

<table>
<thead>
<tr>
<th>System</th>
<th>Bunker footprint</th>
<th>Concrete volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nano-X linac</td>
<td>30 m²</td>
<td>80 m³</td>
</tr>
<tr>
<td>Compact conventional linac</td>
<td>70 m²</td>
<td>160 m³</td>
</tr>
</tbody>
</table>
› ARC LIEF grant support
› Bunker available at Prince of Wales Hospital
› Build …
NEW RADIOTHERAPY TECHNOLOGY:
MRI-Linac
WHY INVEST IN MRI LINACS?

› Ultimate in imaging for guidance: volumetric anatomic information with time giving complete spatio-temporal anatomy
› No implanted markers
› No imaging dose
› Physiologic targeting potential
EXISTING/PROPOSED MRI-LINAC SYSTEMS

U Alberta

Australian MRI-Linac Program

Viewray

U Utrecht

Aus/Canada
67 YR FEMALE WITH RIGHT MID-LOBE NSCLC

- **b-SSFP, ½ NEX**
- **TE/TR: 1.7/3.4**
- **Pixels: 2 × 3 mm²**
- **Slice = 5 mm thick**
- **FOV = 240 × 240 mm²**
- **$T_{acq} = 0.165$ s**

Courtesy Amit Sawant (Stanford)
80 YEAR OLD MALE WITH LEFT UPPER LOBE NSCLC

• b-SSFP, ½ NEX
• TE/TR: 1.7/3.4
• Pixels: 2.4 × 3.3 mm²
• Slice = 5 mm thick
• FOV = 240 × 240 mm²
• Tacq = 0.152 s

Courtesy Amit Sawant (Stanford)
A SPLIT BORE MAGNET: THE GE SIGNA SP
› Equipment specifications completed
› $16M funding secured
  - NHMRC Program grant
  - ARC Discovery Grant
› Separate MRI-simulator purchase process initiated
The Australian MRI-linac Program:
Improving cancer treatment through real-time image guided adaptive radiotherapy

U Sydney: Keall
Baldock/Kim/Kuncic/Thwaites
Fast MR image acquisition
Deformable image registration
Real-time treatment adaptation
Rotating couch development

U Queensland: Crozier
Fay/Rose
Magnet, gradient coil and RF performance
2nd generation rotating system design
Exploratory physiologic targeting

Liverpool/IHRI/UNSW: Barton
Delaney/Forstner/Holloway/Vial
Build research bunker and MRI-linac
Integrated system measurements
Dosimetric validation with EPID
Health technology assessment
Translating research into policy

U Newcastle: Greer
Intrafraction monitoring with EPID

Stanford: Fahrig/Pelc/Scott
Electron gun/waveguide simulations

U Wollongong: Metcalfe/Oborn/Rozenfeld
Detector development
Treatment head/patient transport simulations
Proton therapy simulations

U Western Sydney: Price
Nanoscale contrast agents
SUMMARY
SUMMARY

› Previous technological innovations have resulted in major improvements in cancer treatment outcomes
› Several new technological innovations ongoing
› Opportunities for collaboration for development and translational clinical research

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