Robot-assisted Brachytherapy

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Disclosure

I have no conflicts of interest to disclose.

Learning Objectives

Objectives are to -

• Be familiar with various robotic streams for brachytherapy
• Understand the requirements of brachy-robots
• Be familiar with AAPM TG-192
• Understand the commissioning, and brachy-robots
• Understand the challenges and future directions of robot-assisted brachytherapy
Outline

1) Robots & classification
2) Brachytherapy requirements
3) Available/developed robotic systems
4) AAPM and GEC-ESTRO guidelines (TG-192)
5) Clinical workflow of robotic brachytherapy
6) Robotic system comm. and quality management
7) Challenges and Future Directions

What is meant by a “ROBOT”?

“A robot is a reprogrammable multi-functional manipulator designed to move materials, parts, tools, or specialized devices, through variable programmed motions for performance of a variety of tasks.”

Variation of Robots

- Robot fiction
- Humanoid robot
- Underwater robots
- Space robot (e.g., Rovers)
- Industrial robots
- Medical robots
Robot Classification (mainly based on autonomy)

### Class 1. Devices that manipulate objects with manual control.

### Class 2. Automated devices that manipulate objects with predetermined cycles.

### Class 3. Programmable and semi-controlled robots with continuous point-to-point trajectories.

### Class 4. Robots of this last type that also acquire information from the environment and move intelligently in response.

### Brachy Robots in TG-192

**Level I.** A human controls each movement; each machine actuator change is specified by the operator. Most surgical robots fall into this category.

**Level II.** A human specifies general moves or position changes and the machine decides specific movements of its actuators. Some brachytherapy robots fall into this category.

**Level III.** The operator specifies only the task; the robot manages to complete it independently. Developers of some advanced brachytherapy robots are working to achieve this level of autonomy.

**Level IV.** The machine will create and complete all its tasks without human interaction. This level of autonomy is beyond the capability of current brachytherapy devices.

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**Robot-assisted Surgical/Brachy Paradigm**

- Point & Click Surgery – close the loop in the image
- One Stop Shopping – plan, do, and validate
- Plug & Play Surgery – rapid assembly and certification

**Imager:** CT, MRI, Assistant

**Coordinates:** US, X-ray

**Physician:**

**Planning & control computer:**

**Digital Images:**

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**Conventional Prostate Seed Implant (PSI)**

- Fixed template – limited maneuverability
- PAI – needle angulation difficult
- Consistency, accuracy, efficiency – techniques & human factors
- Clinicians’ fatigue, commitment

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*Podder, AAPM 2018*

*Fichtinger et al. IEEE AIPR, 2001*

*Fichtinger et al. IEEE AIPR, 2001*
Main Objectives are to:

1) Improve accuracy of needle/catheter placement
2) Improve consistency of source placement/delivery
3) Improve avoidance of OARs
4) Improve dose optimization
5) Reduce the clinician’s learning curve
6) Reduce clinician’s fatigue
7) Reduce radiation exposure to clinical staff
8) Streamline the brachytherapy procedure

Functional Requirements:

1) Safety for the patient, clinician staff and equipment
2) Ease of cleaning and decontamination
3) Compatibility with sterilization of components
4) Methods to review and approve the planned dose distribution and planned robot motions
5) Visual (mandatory) and force (optional) feedback
6) Provision for reverting to conventional manual brachytherapy
7) Quick and easy disengagement in case of emergency
8) Robust and reliable operation
9) Ease of operation in the OR environment

How to achieve the goals?

Seed delivery accuracy –
- needle placement accuracy (motorized motion, high resolution encoders, velocity modulation)
- prostate stabilization
- seed immobilization

Avoidance of critical structures (pubic bone, rectum, bladder, urethra) –
- visual feedback
- haptic/force feedback

Compensation for edema, deformation/displacement –
- real time monitoring
- dynamic planning
- flexible maneuverability
- adaptive feedback control-loop

Safety and reliability –
- simple design, standard quality parts, redundant sensors, mechanical stops,
- ease of cleaning, decontamination and sterilization
- hazard analysis & mitigation (EMC test, IEC-60601, FDA, IRB)
- rigorous testing before clinical trial
- periodic QA
Design Space for robots

Robot Components for Brachy

**Hardware:**
- Linkage/mekanism
- Motors/actuators
- Encoders/sensors
- TRUS, CT, MRI
- Image grabber
- CPU (computer)
- Display unit
- Power supply, amplifier

**Software:**
- Patient information handling
- Image acquisition
- Delineation of anatomic structures
- Dosimetric planning
- Needle tracking, seed detection
- Motion control and coordination
- 2D-3D visualization
- Position, vel., force feedback

Design Space for robots

Degree-of-freedom (DOF)

The number of degrees of freedom is equal to the total number of independent displacements (rotation/translation) or aspects of motion.

How many DOF required to just needle insertion (pushing) in prostate or breast?

Robotic systems for brachytherapy
Available/developed robotic systems for brachytherapy

1) Thomas Jefferson University, USA (2) – Podder, Yu
2) Johns Hopkins University, USA (4) – Fichtinger, Stoianovici, Song
3) University of Wisconsin, USA (1) – Thomadsen, et al.
4) University of British Columbia, Canada (1) – Salcudean, Spadinger
5) Robarts Research Institute, Canada (1) – Fenster, et al.
6) University of Western Ontario, Canada (1) – Patel, et al.
7) Elekta/Nucletron - SeedSelectron/FIRST, Netherlands (1) – Elekta
8) Univ. Medical Center Utrecht, Netherlands (1) – Moerland, Lagerburg
9) Grenoble University Hospital, France (1) – Troccaz, Hung
10) Univ. of California at San Diego/ Univ. of Iowa (1) – Watkins, Song
11) Univ. of Cluj-Napoca, Romania (1) – Galdău, Pîslă
12) Tianjin Univ, China (1) – Dou, Yang, et al.

Total = 16

* Daniel (Danny) Song, MD
Robotic Systems for HDR (Dynamic Modulated Brachytherapy)

- DMBT – Dynamic Modulated BrachyTherapy (from UCSD/UI)
- ICBT – Intracavitary BT
- RSBT – Rotating Shield BT
- IS – Interstitial (needle)

Yang, Song, et al., PMB 2013

CT-guided Robotic System for Lung Brachy

Robot-assisted seed implantation for lung cancer.

Used this system for treating over 30 NSCL patients since 2015.

Dou, Yang et al., MedPhys 44(9), 2017
AAPM and GEC-ESTRO Guidelines for Image-Guided Robotic Brachytherapy: Report from Task Group 192

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Adam Dicker, MD, PhD**  Danny Song, MD**
Aaron Fenster, PhD*  Bruce Thomadsen, PhD
Gabor Fichtinger, PhD*  Yan Yu, PhD

* - engineer
** - radiation oncologist

TG-192 Recommendations

Ten major recommendations in TG-192:
1. An emergency reset to default to either semiautonomous or resting mode.
2. Clinicians should have the capability to control the robot at any desired time.
3. The robotic system should have the capability of correcting for needle deviation, and compensating for organ/tissue deflection/deformation.
4. There should be documented policies and procedures for independent check and data verification by the user before robotic execution begins.
5. The TPS should provide the clinicians an intuitive guidance interface.
6. It is recommended that needle insertion be performed in a sequential order by the robot as in current brachytherapy practice.
7. Both robot-clinician and robot-patient interactions should be designed to ensure robustness, reliability, and safety.
8. Care must be taken to avoid exerting excessive force on radioactive sources.
9. Delivery confirmation of the required number of seeds must be maintained through one or multiple methods.
10. All movements of the robot must be verified or checked to avoid potential physical injury as well as collision with the OR environment.

Clinical Workflow
**Commissioning**

- **Acceptance** testing assures that the robotic system satisfies all agreed-upon specifications between the vendor and the buyer.
- **Commissioning** of a robot for clinical use should include:
  - a) verification of dosimetric planning system
  - b) testing of robot’s accuracy and functionalities
  - c) development of operational procedures
  - d) training of procedure related personnel

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**Robot Calibration**

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**Commissioning - Test Protocol**

Parameters need to be evaluated:
1) Positional accuracy of needle tip
2) Repeatability of needle tip position
3) Positional accuracy of the delivered/placed sources
4) Robot-to-imager calibration accuracy
5) Qualitative assessment of tissue damage (if needle rotation provision is used)

**Expt. Results**

<table>
<thead>
<tr>
<th>System</th>
<th>X-error (mean ± SD, mm)</th>
<th>Y-error (mean ± SD, mm)</th>
<th>Z-error (mean ± SD, mm)</th>
<th>3D-error (mean ± SD, mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>s #1</td>
<td>0.18 ± 0.89</td>
<td>0.43 ± 0.26</td>
<td>0.42 ± 0.83</td>
<td>0.63 ± 0.72</td>
</tr>
<tr>
<td>s #2</td>
<td>0.36 ± 0.53</td>
<td>0.48 ± 0.64</td>
<td>0.40 ± 0.52</td>
<td>0.72 ± 0.57</td>
</tr>
</tbody>
</table>
Quality Assurance (QA)

- What to check?
  - Functionality
  - Safety related
  - Accuracy
  - Reliability

- When to check?
  - Check before each case
  - Monthly QA (?)
  - Quarterly check
  - Annual QA

Challenges

- Brachytherapy is underrated
- Shadowed by proton therapy and IMRT
- Decreasing expertise
- Increasing lack of BT training; needs to shorten and make it popular

Robotic BT devices can be a way to mitigate the above issues.
Challenges

- All 16 robotic systems are different
- Ongoing development and regulatory approval
- Clinical studies in progress, supports are limited
- Only one commercial system (motorizes seed delivery and needle withdrawal), available so far
- TG-192 recommendations need to be implemented
- Making it popular to younger generation

Future Perspectives

Conclusions

At present, an automated robotic system seems to be the best solution for bringing BT back to stage 4 by increasing its availability and consequently, reducing the technique’s learning curve. More advanced technology and advancements are expected to improve their attractiveness to BT, and, consequently, more patients could benefit. For the time-being, the Oncura integrated Prostate Solution device is the only robotic system commercially available for LDR seeds BT. Among a dozen of companies and under development systems, our parallel robot could be a pioneer of the next generation prostate tools in BT.
Future Perspectives

- Using the AAPM-ESTRO TG-192 report the robotic systems will be more standardized for brachytherapy
- Clinical trials/studies are in progress
- Some of the systems are being commercialized (licensed)
- Get new generation physician and physicist involved
- Potentially brachytherapy (LDR & HDR) procedures and outcomes will be improved