AAPM 2018 JUL 29–AUG 2
BEYOND THE FUTURE!

Robot-assisted Brachytherapy

Tarun K. Podder, PhD
Associate Professor
Department of Radiation Oncology
Department of Biomedical Engineering
University Hospitals, Seidman Cancer Center
Case Western Reserve University
Cleveland, OH 44106

Nashville, TN
August 01, 2018

Disclosure

I have no conflicts of interest to disclose.

Podder, AAPM 2018

Learning Objectives

Objectives are to -

- Be familiar with various robotic steams 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

Podder, AAPM 2018

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 (from JPL)

Industrial robots Medical robots

Robot Classification (mainly based on autonomy)

RIA – Robotics Institute of America

Class 1. Devices that manipulate objects with manual control,

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

Class 3. Programmable and servo-controlled robots with continuous point-to-point trajectories, and

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.

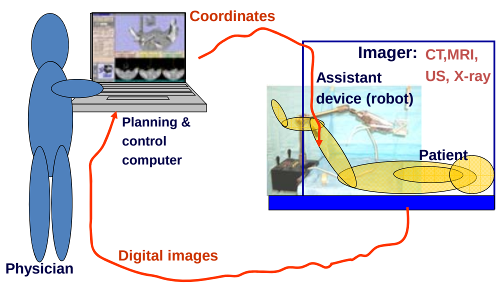
Level IV. The machine will create and complete all its tasks without human interaction. This level of autonomy is beyond the capability of current brachytherapy devices.

AAPM TG-192, MedPhys 41(10), 2014

Podder, AAPM 2018

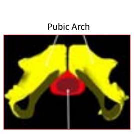
Robot-assisted Surgical/Brachy Paradigm

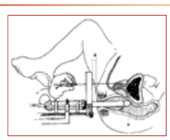
- **Point & Click Surgery – close the loop in the image**
- **One Stop Shopping – plan, do, and validate**
- **Plug & Play Surgery – rapid assembly and certification**

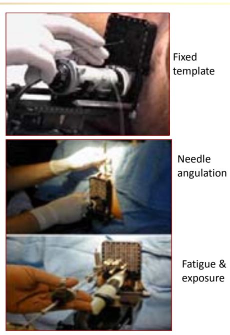


Fichtinger et al. IEEE AIPR, 2001

Conventional Prostate Seed Implant (PSI)







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

Podder, AAPM 2018

Robot-assisted Brachytherapy

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

AAPM TG-192, MedPhys 41(10), 2014

Robot-assisted Brachytherapy

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

AAPM TG-192, MedPhys 41(10), 2014

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

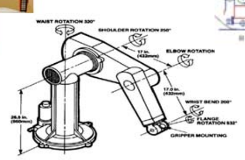
Hardware:
- Linkage/ mechanism
- Motors/ actuators
- Encoders/ sensors
- TRUS,CT, MRI
- Image grabber
- CPU (computer)
- Display unit
- Power supply, amplifier

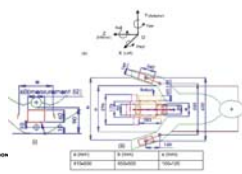
Software:
- Patient information handling
- Image acquisition
- Delineation of anatomic structures
- Dosimetric planning
- Needle tracking, seed detection
- Motion control and coordination
- 2D-3D visualization
- Position, vel., force feedback

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.



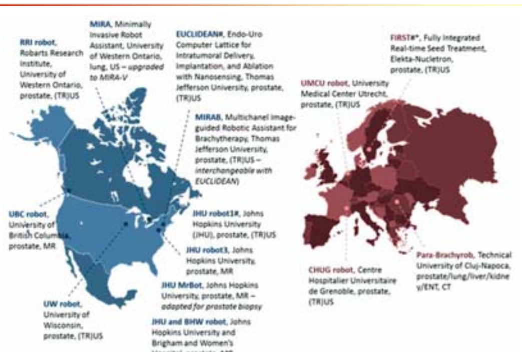


AAPM TG-192, 2014

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

Podder, AAPM 2018

Robotic systems for brachytherapy



Popescu et al., J. Cont. Barchy 7(6), 2015

Podder, AAPM 2018

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 Colombia, 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, Hungr
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

Summary of Brachy Robots

Total = 16 (1 not listed here, shown later)
13 were reported in AAPM TG-192

Table 1: Summary of the currently available robotic brachytherapy systems.

Features	TRUS-based Robotic Prostate Brachytherapy Systems	MR-based Robotic Prostate Brachytherapy Systems	US-based Robotic Brachytherapy Systems for Other Organs

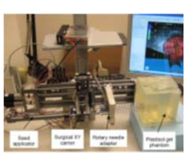
Some of the Brachy Robots

Stoianovici, Roach, *et al.* MITAT, 2010

Fichtinger *et al.* MedIA, 2008

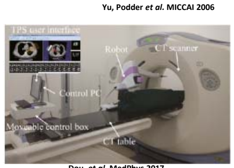
Hungr, *et al.* IEEE-EMBS, 2009

Yu, Podder *et al.* MICCAI 2006



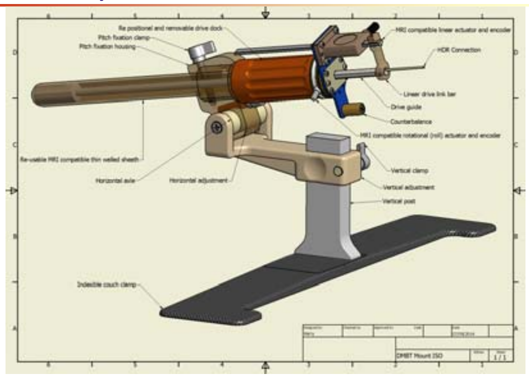
Podder et al. IEEE-BIBE 2010

Salcudean et al. IEEE-ICRA 2010



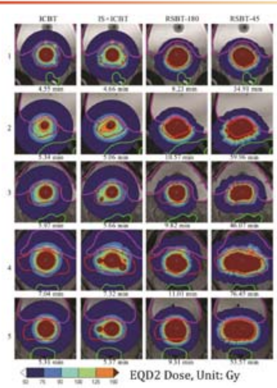
Dou, *et al.* MedPhys 2017
(4DOF CT-guided for lung brachy)

Robotic Systems for HDR (Dynamic Modulated Brachytherapy)



DMBT - Dynamic Modulated BrachyTherapy (from UCSD/UI)

Robotic Systems for HDR (Dynamic Modulated Brachytherapy)

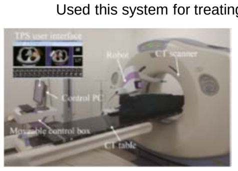


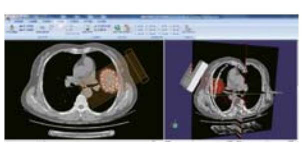
ICBT – Intracavitary BT
RSBT – Rotating Shield BT
IS – Interstitial (needle)

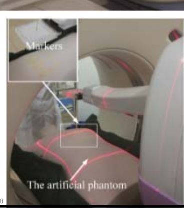
Yang, Song, et al., PMB 2013

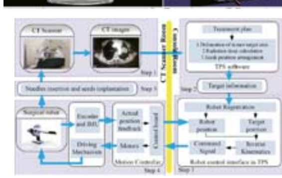
CT-guided Robotic System for Lung Brachy

Robot-assisted seed implantation for lung cancer.
Used this system for treating over 30 NSCL patients since 2015.









Podder, AAPM 2018

Dou, Yang et al., MedPhys 44(9), 2017

AAPM and GEC-ESTRO Guidelines for Image-Guided Robotic Brachytherapy: Report from Task Group 192

Tarun Podder, PhD (chair)
Luc Beaulieu, PhD
Barrett Caldwell, PhD*
Robert Cormack, PhD
Jostin Crass, MS
Adam Dicker, MD, PhD**
Aaron Fenster, PhD*
Gabor Fichtinger, PhD*
Michael Meltsner, PhD
Marinus Moerland, PhD
Ravinder Nath, PhD
Mark Rivard, PhD
Tim Salcudean, PhD*
Danny Song, MD**
Bruce Thomadsen, PhD
Yan Yu, PhD

* - engineer
** - radiation oncologist

AAPM TG-192, MedPhys 41(10), 2014

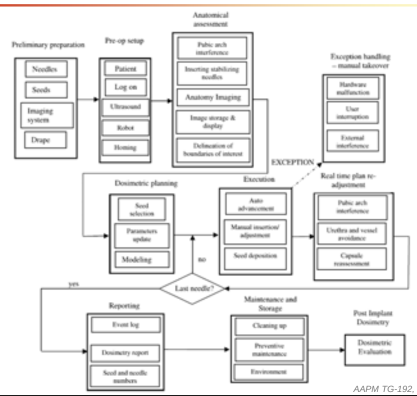
TG-192 Recommendations

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.

Podder et al.: Report of Task Group 192 — Medical Physics, Vol. 41, No. 10, October 2014

Clinical Workflow



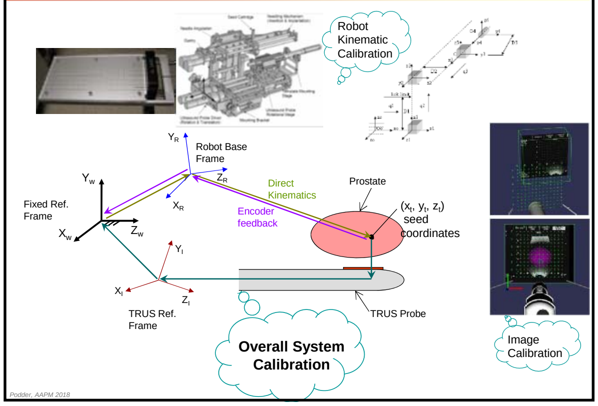
Podder, AAPM 2018 — *AAPM TG-192, MedPhys 41(10), 2014*

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

Podder, AAPM 2018

Robot Calibration



Podder, AAPM 2018

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

System	x-error (mean ± SD, mm)	y-error (mean ± SD, mm)	z-error (mean ± SD, mm)	3D-error (mean ± SD, mm)
# 1	0.18 ± 0.89	0.43 ± 0.26	0.42 ± 0.83	0.63 ± 0.72
# 2	0.36 ± 0.53	0.48 ± 0.64	0.40 ± 0.52	0.72 ± 0.57

Podder, AAPM 2018

Quality Assurance (QA)

- What to check?
  - Functionality
  - Safety related
  - Accuracy
  - Reliability
- When to check?
  - Check before each case
  - Monthly QA (?)
  - Quarterly check
  - Annual QA

QA check prior to the procedure

Jefferson. University Hospitals — Department of Radiation Oncology

Preoperative Quality Assurance of EUCLIDIAN – Image-guided Robotic System for Prostate Brachytherapy

I MECHANICAL SCREENING TEST

1 Visual check
2 Connectivity
3 Sensors
4 Needling Mechanism
5 Other

II ROBOT FUNCTIONALITY TEST

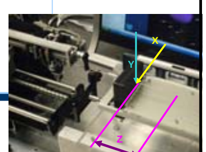
1 Hardware detection
2 Mobility
3 Case test

III IMAGING MODULE TEST

1 Image calibration
2 Precision

Accuracy	X	Y	Z
[illegible] 1 – point 1			
[illegible] 1 – point 2			
[illegible] 2 – point 1			
[illegible] 2 – point 2			

Physicist Date



Buzurovic, Podder, Yu, et al., AAPM 2008

Challenges

Original paper

J Contemp Brachytherapy 2015; 7, 6: 510–514
DOI: 10.5114/jcb.2015.56769

Brachytherapy next generation: robotic systems

Tiberiu Popescu, MSc[1], Alex Cristian Kacsó, MSc[1], Prof. Doina Pisla, PhD[2], Assoc. Prof. Gabriel Kacsó, MD, PhD[1,3]
[1]Iuliu Hațieganu" University of Medicine and Pharmacy, Cluj-Napoca, [2]Technical University of Cluj-Napoca, The Research Center for Industrial Robots Simulation and Testing, Cluj, [3]Department of Radiation Oncology and Medical Oncology, RTC Amethyst Cluj, Romania

Abstract

In a field dominated by external beam radiation therapy (EBRT), both the therapeutic and technical possibilities of brachytherapy (BT) are underrated, shadowed by protons and intensity modulated radiotherapy. Decreasing expertise and indications, as well as increasing lack of specific BT training for radiation therapy (RT) residents led to the real need of shortening its learning curve and making it more popular. Developing robotic BT devices can be a way to mitigate the above issues. There are many teams working at custom-made robotic BT platforms to perfect and overcome the limitations of the existing systems. This paper provides a picture of the current state-of-the-art in robotic assisted BT, as it also conveys the

- 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

Original paper
J Contemp Brachytherapy 2015; 7, 6: 510-514
DOI: 10.5114/jcb.2015.56769

Brachytherapy next generation: robotic systems

Tiberiu Popescu, MSc[1], Alex Cristian Kacsó, MSc[1], Prof. Doina Pisla, PhD[2], Assoc. Prof. Gabriel Kacsó, MD, PhD[1,3]
[1]Iuliu Hatieganu" University of Medicine and Pharmacy, Cluj-Napoca, [2]Technical University of Cluj-Napoca, The Research Center for Industrial Robots Simulation and Testing, Cluj, [3]Department of Radiation Oncology and Medical Oncology, RTC Amethyst Cluj, Romania

For some, brachytherapy (BT) is something on the brink of extinction and their arguments are not scarce. Brachytherapy might not sound too appealing for the average radiation oncologist because it implies transition from behind the screen to the OR. Blood appears as a real scenario and most of them chose from the beginning to avoid it willingly. It is not only about the lack of surgical skills, but also that most junior radiation oncologists do not actually have the chance to see or practice the technique in their centers. Moreover, BT is by itself a niche domain, as there are rather few indications for it, as compared to external beam radiotherapy (EBRT). Therefore, for most of them, BT is something more like "see not touch". Last but not least, in a domain driven by EBRT, investing in BT might not seem too appealing for developers.

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

Original paper
J Contemp Brachytherapy 2015; 7, 6: 510-514
DOI: 10.5114/jcb.2015.56769

Brachytherapy next generation: robotic systems

Tiberiu Popescu, MSc[1], Alex Cristian Kacsó, MSc[1], Prof. Doina Pisla, PhD[2], Assoc. Prof. Gabriel Kacsó, MD, PhD[1,3]
[1]Iuliu Hatieganu" University of Medicine and Pharmacy, Cluj-Napoca, [2]Technical University of Cluj-Napoca, The Research Center for Industrial Robots Simulation and Testing, Cluj, [3]Department of Radiation Oncology and Medical Oncology, RTC Amethyst Cluj, Romania

Conclusions

At present, automate (partial or full procedure) seems to be the best solution for bringing BT back to stage. By increasing its availability and consequently reducing the technique's learning curve, more junior radiation oncologists are expected to turn their attention to BT, and, consequently, more patients could benefit. For the time-being, the Oncentra Integrated Prostate Solution device is the only robotic system commercially available for LDR seeds BT. Among a dozen of custom-made and under development systems, our parallel robot Para-Brachyrob, thanks to its versatility and technical capabilities, might be a pioneer of the next generation precision 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

Podder, AAPM 2018