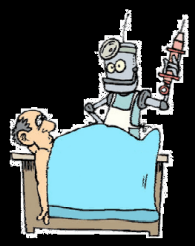
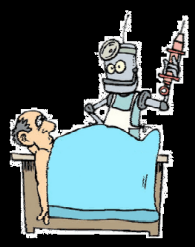


Recent Technology Innovations in Prostate Brachytherapy

J. Adam M. Cunha, Ph.D.
University of California (UCSF)
San Francisco, CA

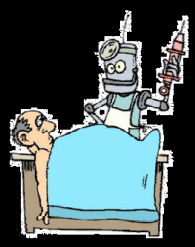
Image credit: www.patrickweb.com/wordpress/2010/11/21/2008



Disclosure

Partial research support from Philips Healthcare

Image credit: www.patrickweb.com/wordpress/2010/11/21/2008



Learning Objectives.
Upon completion of this lecture you will have:

A knowledge of the TG-192 report and the current status of robotic brachytherapy;

An understanding of image-guided adaptive brachytherapy in the context of prostate.

A familiarity with electromagnetic (EM) tracking and its potential use in brachytherapy

Image credit: www.patrickweb.com/wordpress/2010/11/21/2008

Robots in Brachytherapy: Motivation

In skilled hands, brachytherapy works

12-YEAR OUTCOMES FOLLOWING PERMANENT PROSTATE BRACHYTHERAPY IN PATIENTS WITH CLINICALLY LOCALIZED PROSTATE CANCER

LOUIS POTTERS,* CAROL MORGENSTERN, EMIL CALUGARU, PAUL FRANK, ANUP JABBAL

90% survival at 12 y

PHASE II TRIAL OF COMBINED HIGH-DOSE-RATE BRACHYTHERAPY AND EXTERNAL BEAM RADIOTHERAPY FOR ADENOCARCINOMA OF THE PROSTATE: PRELIMINARY RESULTS OF RTOG 0321

I-Chow Hsu, M.D.,* Kyounghwa Bae, Ph.D.,† Katsuto Shinohara, M.D.,* Jean Pouliot, Ph.D.,*

Combined modality treatment with high-dose-rate brachytherapy boost for locally advanced prostate cancer

I-Chow J. Hsu[1,2], Alvin R. Cabrera[1], Vivian Weinberg[1], Joycelyn Speight[1], Alexander R. Gottschalk[1], Mack Roach III[1], Katsuto Shinohara[1]

[1]Department of Radiation Oncology, University of California San Francisco, San Francisco, CA

98% survival at 4 y

But side effects can be significant (especially if procedure skill is nominal)

A NEW MODEL USING NUMBER OF NEEDLES AND ANDROGEN DEPRIVATION TO PREDICT CHRONIC URINARY TOXICITY FOR HIGH OR LOW DOSE RATE PROSTATE BRACHYTHERAPY

CARLOS VARGAS, MICHEL GHILEZAN,* MITCHELL HOLLANDER, GARY GUSTAFSON, HOWARD KUBIAN, JOSE GONZALEZ AND ALVARO MARTINEZ

41% impotence

26% G3+ UT

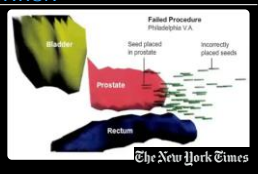
Ideal Plan → Uncertainty and Needle/Tissue Interaction → Executed Plan

Robots in Brachytherapy: Motivation

Ideal Plan → Uncertainty and Needle/Tissue Interaction → Executed Plan

Executed ≠ Planned

Robots can mitigate



- Surgical procedure – Highly skill dependent – learning curve
- # of needle insertions required is an inverse function of years of experience
- Needle puncture trauma to target and normal tissues
- Imaging access (real-time feedback needed for needle insertion)
- Geometric restrictions to brachytherapy. E.g. Pubic arch interference
- Hard to intra-operatively "fix" misplacements

Working Group on Robotic Brachytherapy

- Commenced in 2008 under the Brachytherapy SC of Therapy Physics Committee
- Convened Task Group 192 to work with GEC-ESTRO brachy group.

Charge

1. Introduction to robotic brachytherapy: History, classifications, definitions, nomenclature.
2. Review of current research and development - approaches and systems for procedures like brachytherapy, biopsy, etc.
3. QA & calibration issues - robotic space, patient space, design & development issues, safety & reliability issues, hazard analysis, FTA & FMECA analysis, system calibration.
4. Recommendations for robotic brachytherapy - guidelines for robot assisted brachytherapy procedures.
5. Future development - suggestions for improvement.

- Culminated in 2014: "AAPM and GEC-ESTRO guidelines for image-guided robotic brachytherapy: Report of Task Group 192" Medical Physics, Vol 41, Issue 10 (2014).

Robot Definition

Simple **Definition** of **robot**. : a real or imaginary machine that is controlled by a computer and is often made to look like a human or animal. : a machine that can do the work of a person and that works automatically or is controlled by a computer.

The **Robotic Industries Association** (**RIA**) defines **robot** as follows: "A **robot** is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks."

Robot Classifications

Robotics Institute of America:

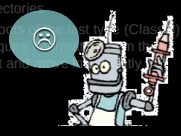
- Class 1: Devices that manipulate objects with manual control
- Class 2: Automated devices that manipulate objects with predetermined cycles
- Class 3: Programmable and servo-controlled robots with continuous point-to-point trajectories
- Class 4: Robots of the last type (Class 3) that also acquire information from the environment and move intelligently in response

Ex Machina Universal Pictures (2015)
Anthropomorphic

Robot Classifications

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
- Class 4: Robots of the last type (Class 3) that also acquire information from the environment and move intelligently in response



Ex Machina Universal Pictures (2015)
Anthropomorphic

Robot Classifications

Robotic Industries Association:

- 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
- Class 4: Robots of the last type (Class 3) that also acquire information from the environment and move intelligently in response

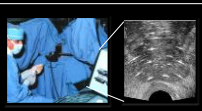
For brachytherapy, TG-192:

- Level I. A human controls each movement; each machine actuator change is specified by the operator.
- Level II. A human specifies general moves or position changes and the machine decides specific movements of its actuators.
- Level III. The operator specifies only the task; the robot manages to complete it independently.
- Level IV. The machine will create and complete all its tasks without human interaction.

Robot Classifications

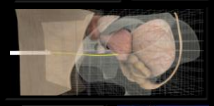
Humans

Need real-time imaging



Robots - Stereotactic

Fixed coordinate system



Robots - Servo

Extension of a human

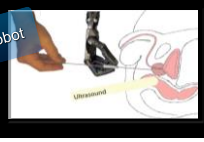
Humans, robots: different strengths

Tele-robotics

Mitigate skill/geography disparity

Co-Robots

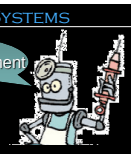
Integration of human and robot



TG-192 Requirements of Medical Robotic Systems

1. Safety for the patient, clinicians, and staff,
2. Ease of cleaning and decontamination,
3. Compatibility with sterilization,
4. Methods for review of planned dose distributions and robot motions before needle placement,
5. Visual (mandatory) and force (optional) feedback during needle insertion,
6. Visual confirmation of each needle-tip placement and seed deposition,
7. Provision for reverting to conventional manual brachytherapy at any time,
8. Quick and easy disengagement in case of emergency,
9. Robust and reliable operation, and
10. Ease of operation in the procedure environment.

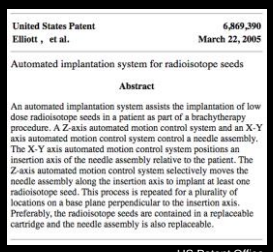
TG-192 Goals for Brachytherapy Robotic Systems



1. Improve …accuracy of needle placement and seed delivery (i.e., place the needle and seed correctly at the planned location),
2. …consistency of seed implantation procedure (i.e., eliminate inter-clinician variability),
3. …avoidance of critical structures (e.g., for prostate implants, urethra, pubic arch, rectum, bladder, structures of the penis),
4. …dose optimization,
5. Reduce …the clinician's learning curve,
6. …clinician fatigue,
7. …staff radiation exposure, and
8. Streamline the brachytherapy procedure.

First brachytherapy robots

- 2001 Elliot et al.: US patent for a seed implantation system featuring automated XYZ motion with a seed cartridge.

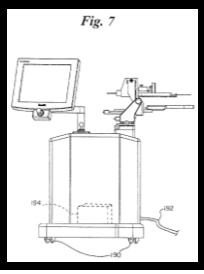


United States Patent 6,869,390
Elliott , et al. March 22, 2005

Automated implantation system for radioisotope seeds

Abstract

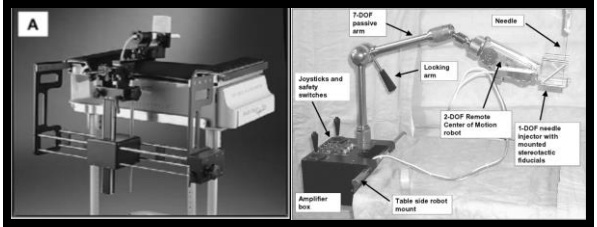
An automated implantation system assists the implantation of low dose radioisotope seeds in a patient as part of a brachytherapy procedure. A Z-axis automated motion control system and an X-Y axis automated motion control system control a needle assembly. The X-Y axis automated motion control system positions an insertion axis of the needle assembly relative to the patient. The Z-axis automated motion control system selectively moves the needle assembly along the insertion axis to implant at least one radioisotope seed. This process is repeated for a plurality of locations on a base plane perpendicular to the insertion axis. Preferably, the radioisotope seeds are contained in a replaceable cartridge and the needle assembly is also replaceable.



US Patent Office

First brachytherapy robots

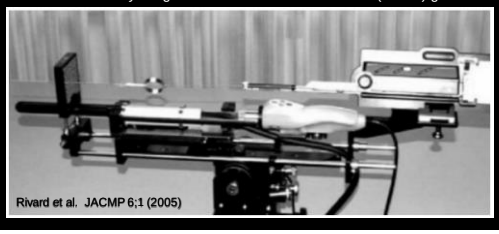
- 2001 Elliot et al.: US patent for a seed implantation system featuring automated XYZ motion with a seed cartridge.
- 2002 Fichtinger et al.: CT-guided robot assistance for prostate biopsy and therapy.



Fichtinger et al. Academic Radiology 9(1) 2002

First brachytherapy robots

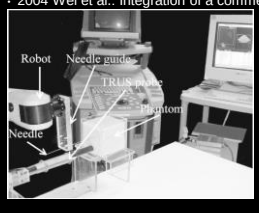
- 2001 Elliot et al.: US patent for a seed implantation system featuring automated XYZ motion with a seed cartridge.
- 2002 Fichtinger et al.: CT-guided robot assistance for prostate biopsy and therapy.
- 2002 Nucletron: Fully Integrated Real-time Seed Treatment (FIRST) goes to market



Rivard et al. JACMP 6;1 (2005)

First brachytherapy robots

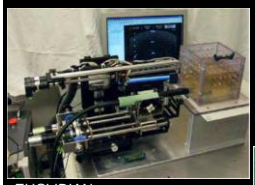
- 2001 Elliot et al.: US patent for a seed implantation system featuring automated XYZ motion with a seed cartridge.
- 2002 Fichtinger et al.: CT-guided robot assistance for prostate biopsy and therapy.
- 2002 Nucletron: Fully Integrated Real-time Seed Treatment (FIRST) goes to market
- 2004 Wei et al.: Integration of a commercial robot into the prostate brachy workflow.



Wei, Fenster, et al. MedPhys 31(3) 2004

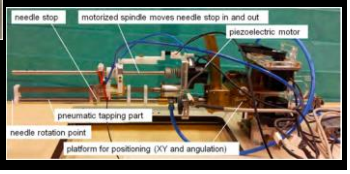
TG-192 reported on 13 robots in development

All images from TG-192



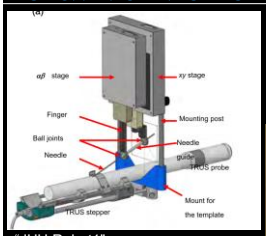
EUCLIDIAN
Yu, Podder, et al.
Thomas Jeffereson Univ.

UMCU (Utrecht) MRI-guided robotic system
Largerburg et al.



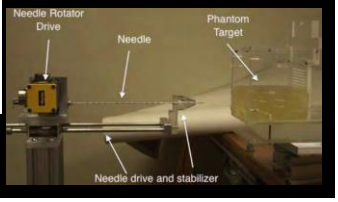
TG-192 reported on 13 robots in development

All images from TG-192



"JHU Robot1"
Fichtinger, et al.

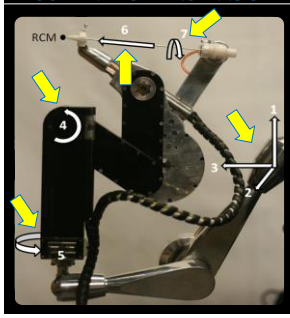
UW Robot
Meltsner et al.



Classifications of 13 TG-192 Robots

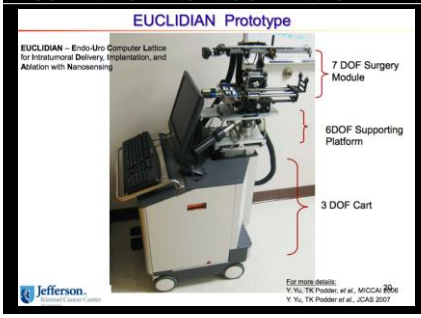
Robot	Use	Imaging	DoF	Autonomy Class
FIRST (Nucletron)	PSI	US	2	Level II
EUCLIDIAN (TJU)	PSI	US	5 + 6	Level III
MIRAB (TJU)	PSI/HDR	US	5 + 6	Level III
UMCU robot	PSI/HDR	MR	5	Level II
UW robot	PSI/HDR	US	6	Level II
JHU robot1	PSI	US	4	Level I
MrBot (JHU)	PSI	MR	4	Level III
JHU3-MR	PSI	MR	3	Level II
BWH-MR (JHU)	PSI	MR	6	Level II
UBC	PSI	US	4	Level II
RRI	PSI	US	4	Level II
CHUG	PSI	US	5	Level II
MIRA-V (UWO)	Lung seeds	US	5	Level II

A comment on Degrees of freedom



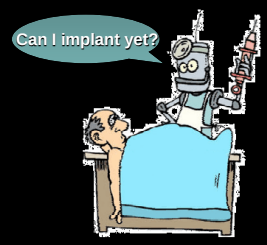
- Degrees of freedom (DoF) define the ability of the robot to be positioned in space to place a needle or seed. It is based on dimensionality of the motion to be executed.
- Placement of the robot's shoulder in (x,y,z) for positioning: 3 DoF
- Parallel movement of the needle in an x-y coordinate system (not shown): 2 DoF
- Rotation of needle about tip location or other RCM (pitch, yaw): 2 DoF
- Insertion of needle: 1 DoF
- Rotation (rifling) of the needle about axis: 1 DoF

A comment on Degrees of freedom



Degrees of freedom =
7 + 6 + 3

Clinical Trials



Clinical Trials


Contents lists available at ScienceDirect

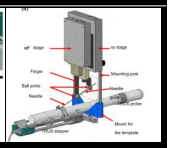
Medical Image Analysis

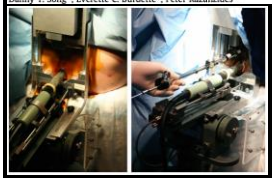
journal homepage: www.elsevier.com/locate/media

Medical Image Analysis 12 (2008) 535–545

Robotic assistance for ultrasound-guided prostate brachytherapy

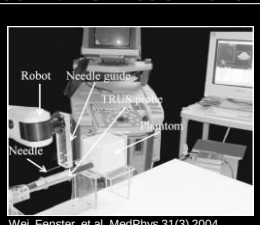
Gabor Fichtinger [a,b,*], Jonathan P. Fiene [c], Christopher W. Kennedy [b], Gernot Kronreif [d], Iulian Iordachita [b], Danny Y. Song [b], Everette C. Burdette [e], Peter Kazanzides [b]





- First in 2008: 5 patients on Phase I trial
- Average 36 needles per plan inserted using robot guidance.

Current Status of Robots from TG-192 Report



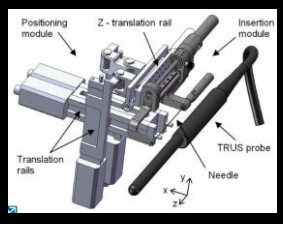
Wei, Fenster, et al. MedPhys 31(3) 2004

- Robarts Research Institute (RRI Robot, Aaron Fenster) licensed to Eigen (Grass Valley, CA)
  - Currently being used in the clinic for HDR brachytherapy
  - Looking to translate to breast and/or gyn.

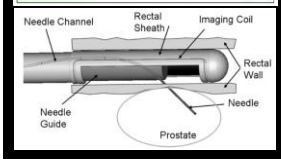
Current Status of Robots from TG-192 Report

Baumman, Troccaz et al. IRBM 32 (2011)

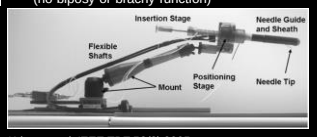
- The Prosper robot (CHUG, France robot) has gone through a design iteration and is now on version 2.
- Preparing protocol for evaluation in patients



Current Status of Robots from TG-192 Report



- JHU3-MR (Axel Krieger) technology was commercialized with Sentinelle Medical Inc., and Hologic.
  - Sentinelle product line is part of InVivo (Philips) prostate biopsy technology.
    - Uses EM tracking too!
  - Also created Sentinelle prostate MR coil (no biposy or brachy function)



Krieger et al. IEEE TBE 52(2) 2005

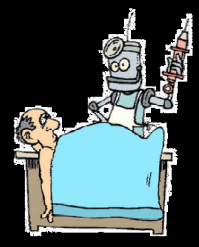


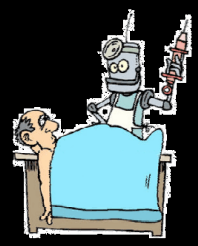
Image credit: www.patrickweb.com/wordpress/2010/11/21/2008

Learning Objectives. Upon completion of this lecture you will have:

A knowledge of the TG-192 report and the current status of robotic brachytherapy;

An understanding of image-guided adaptive brachytherapy in the context of prostate.

A familiarity with electromagnetic (EM) tracking and its potential use in brachytherapy



Learning Objectives.
Upon completion of this lecture you will have:

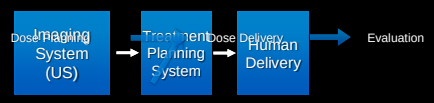
A knowledge of the TG-192 report and the current status of robotic brachytherapy;

An understanding of image-guided adaptive brachytherapy in the context of prostate.

A familiarity with electromagnetic (EM) tracking and its potential use in brachytherapy

Image credit: www.patrickweb.com/wordpress/2010/11/21/2008

Adaptive PPI brachytherapy workflow



Stereotactic robot PPI workflow

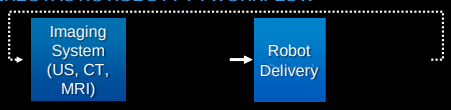


Image Guided Intra-Operative Adaptive Brachy

PPI brachytherapy workflow

1. Image
2. Contour
3. Plan seed & needle positions
4. Place seeds
5. Post implant dose evaluation

PPI adaptive brachytherapy workflow

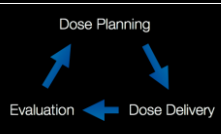
1. Image
2. Contour
3. Plan seed & needle positions
4. Place some seeds
5. Re-image
6. Locate dropped seeds
7. Evaluate contours / re-contour
8. Evaluate dose distribution
9. Re-optimize
10. Place remaining seeds
11. Final implant dose evaluation

Image Guided Intra-Operative Adaptive Brachy

PPI brachytherapy workflow

1. Image
2. Contour
3. Plan seed & needle positions
4. Place seeds
5. Post implant dose evaluation

Dose Planning → Delivery → Evaluation



PPI adaptive brachytherapy workflow

1. Image
2. Contour
3. Plan seed & needle positions
4. Place some seeds
5. Re-image
6. Locate dropped seeds
7. Evaluate contours / re-contour
8. Evaluate dose distribution
9. Re-optimize
10. Place remaining seeds
11. Final implant dose evaluation

Image Guided Intra-Operative Adaptive Brachy

INTRAOPERATIVE PLANNING AND EVALUATION OF PERMANENT PROSTATE BRACHYTHERAPY: REPORT OF THE AMERICAN BRACHYTHERAPY SOCIETY. Nag et al. 51(5) IJROBP (2001)

Table 1. Elements of an intraoperative planning system

Description	Commercially available	Under development
Treatment planning in operating room	X	
Image acquisition	X	
Target definition	X	
Organ segmentation (draw contours manually)	X	
Identify needle position in relation to prostate	X	
Intraoperative optimization based on imaged needle location	X	
Estimate seed positions from imaged needle position	X	
Update dose calculation based on imaged needle location	X	
Auto organ segmentation	X	
Capturing deposited seed positions in real time		X
Optimization based on deposited seed location		X
Dynamic updating of dose calculation based on actual seed position		X
Account for motion of prostate during placement		X
Account for intraoperative edema		X
Postimplant dose calculation at time of surgery		X
Account for postoperative edema		X

4. Place **some** seeds
5. Re-image
6. Locate dropped seeds
7. Evaluate contours / re-contour
8. Evaluate dose distribution
9. Re-optimize

- Continuously mon
  re-optimization if e
  compliant dose pl

Real-time Electromagnetic Seed Drop Detection Validation for Low-Dose-Rate Brachytherapy: An Approach Exploiting RF/Electromagnetic Technologies

AAPM2015; Submitted to Med Phys

Emmanuel Racine, PhD, Dirk Binnekamp, PhD, Gilion Hautvast, PhD, Luc Beaulieu, PhD

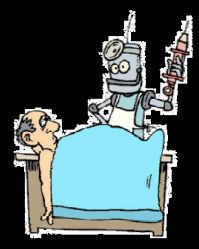


Image credit: www.patrickweb.com/wordpress/2010/11/21/2008

Learning Objectives. Upon completion of this lecture you will have:

A knowledge of the TG-192 report and the current status of robotic brachytherapy;

An understanding of image-guided adaptive brachytherapy in the context of prostate.

A familiarity with electromagnetic (EM) tracking and its potential use in brachytherapy

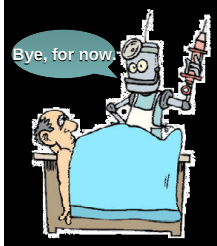


Image credit: www.patrickweb.com/wordpress/2010/11/21/2008

Learning Objectives.
Upon completion of this lecture you will have:

A knowledge of the TG-192 report and the current status of robotic brachytherapy;

An understanding of image-guided adaptive brachytherapy in the context of prostate.

A familiarity with electromagnetic (EM) tracking and its potential use in brachytherapy

What is Electromagnetic (EM) Tracking

- Tracking = Real time guidance
- First papers on concept of using EM fields to track location (1979 & 1980)
- Standardized protocols in 2005 lead to rapid increse in clinical applications.
- Nice review paper:

Image credit: https://c2.staticflickr.com/8/7022/6690662375_45a2e78470_b.jpg

1702 IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 33, NO. 8, AUGUST 2014

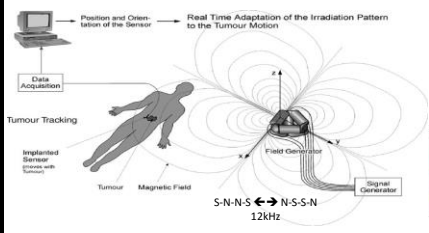
Electromagnetic Tracking in Medicine—A Review of Technology, Validation, and Applications

Alfred M. Franz*, Tamás Haidegger, Wolfgang Birkfellner, Kevin Cleary, Terry M. Peters, and Lena Maier-Hein

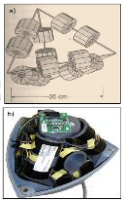
Slide Courtesy of Luc Beaulieu (ABS 2016)

Planar field generator - AC

NDI Aurora system (théorie Seiler *et al.* PMB 2000)



Six differential coils



Slide Courtesy of Luc Beaulieu (ABS 2016)

Planar field generator - AC

- Sensor = induction coil
- Alternating current of ± 2 A at 12 kHz for 3.3 ms each differential coil will create 6 different voltages at the sensor
- If 5DOF needle: 6 measurements and 5 unknown
- If 6DOF: 2 sensor coils

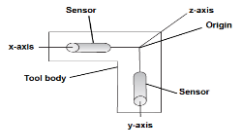
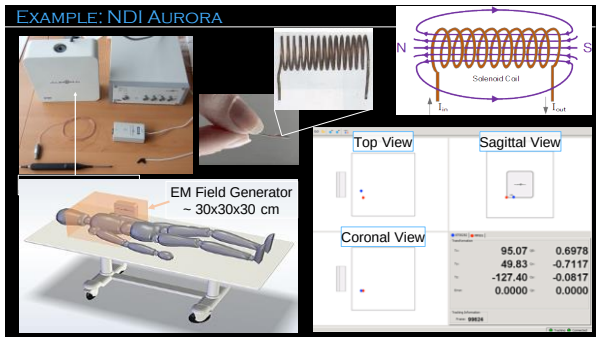


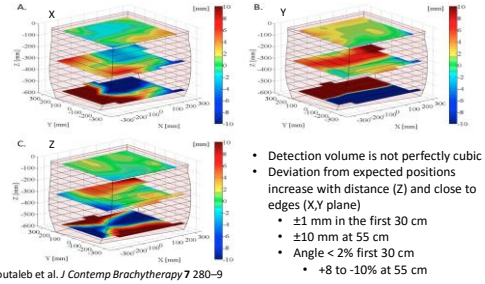
Figure 5-5 Sample 6DOF Tool

Example: NDI Aurora



Slide Courtesy of Luc Beaulieu

Detection Volume



Boutaleb et al. *J Contemp Brachytherapy* **7** 280–9

- Detection volume is not perfectly cubic
- Deviation from expected positions increase with distance (Z) and close to edges (X,Y plane)
  - ±1 mm in the first 30 cm
  - ±10 mm at 55 cm
  - Angle < 2% first 30 cm
    - +8 to -10% at 55 cm

Slide Courtesy of Luc Beaulieu (ABS 2016)

Summary of Performance

- Needs to be used within the first 30 cm of the field generator
- Needle parallel to the field generator yield better angular accuracy
- Field generator generate heat: not under the patient
- Interference seen only for CRT monitor and bulky metalic arms (not shown)
  - Insensitive to US probe and needles/catheters
  - Metal close to the generator (but not within the field) can be OK as long as the configuration does not move/change during the procedure

EM Tracking systems

INTRAOPERATIVE PLANNING AND EVALUATION OF PERMANENT PROSTATE BRACHYTHERAPY: REPORT OF THE AMERICAN BRACHYTHERAPY SOCIETY. Nag et al. 51(5) IJROBP (2001)

Table 1. Elements of an intraoperative planning system

Description	Commercially available	Under development
Treatment planning in operating room	X	
Image acquisition	X	
Target definition	X	
Organ segmentation (draw contours manually)	X	
Identify needle position in relation to prostate	X	
Intraoperative optimization based on imaged needle location	X	
Estimate seed positions from imaged needle position	X	
Update dose calculation based on imaged needle location	X	
Auto organ segmentation	X	
Capturing deposited seed positions in real time		X
Optimization based on deposited seed location		X
Dynamic updating of dose calculation based on actual seed position		X
Account for motion of prostate during placement		X
Account for intraoperative edema		X
Postimplant dose calculation at time of surgery		X
Account for postoperative edema		X

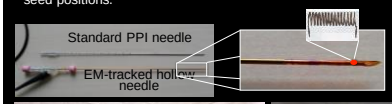
4. Place **some** seeds
5. Re-image
6. Locate dropped seeds
7. Evaluate contours / re-contour
8. Evaluate dose distribution
9. Re-optimize

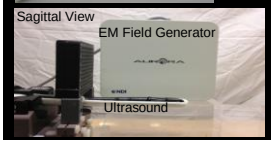
- Continuously monitor implant quality. Trigger an on-the-fly re-optimization if errors in placed seeds will create a non-compliant dose plan.

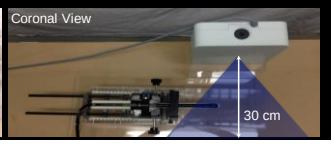
EM Tracking systems

- Continuously monitor implant quality. Trigger an on-the-fly re-optimization if errors in placed seeds will create a non-compliant dose plan.
- Use electromagnetic tracking to detect needle AND actual seed positions.

4. Place **some** seeds
5. Re-image
6. Locate dropped seeds
7. Evaluate contours / re-contour
8. Evaluate dose distribution
9. Re-optimize







Slide Courtesy of Luc Beaulieu (ABS 2016)

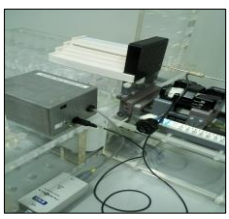
Seed drop position

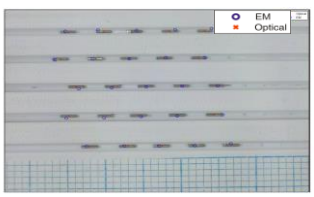
A hollow brachytherapy electromagnetic needle prototype was recently developed by Philips Healthcare.

- ✓ Detects seed drops by exploiting local changes of electromagnetic properties in the medium.
- ✓ Preserves standard tacking capabilities.

Slide Courtesy of Luc Beaulieu (ABS 2016)

Seed drop position





Slide Courtesy of Luc Beaulieu (ABS 2016)

Seed drop position

Registration of detected seed distributions. True seed positions were obtained from a μCT scan (GE, 89 μm slice thickness).

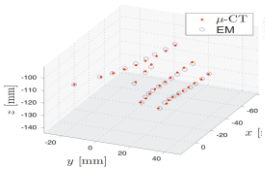


TABLE III. Statistics of the seed drop position estimates for the 3D characterization experiment.

	Error measurements [mm]			
	Minimum	Maximum	Average	Std dev.
$\lvert e_x \rvert$	$0.0^{+0.1}_{-0.0}$	$0.6^{+0.5}_{-0.1}$	$0.2^{+0.5}_{-0.3}$	$0.1^{+0.3}_{-0.1}$
$\lvert e_y \rvert$	$0.0^{+0.2}_{-0.0}$	$0.7^{+0.5}_{-0.2}$	$0.2^{+0.5}_{-0.3}$	$0.1^{+0.3}_{-0.1}$
$\lvert e_z \rvert$	$0.1^{+1.0}_{-0.1}$	$2.1^{+1.0}_{-1.7}$	$0.4^{+1.0}_{-0.4}$	$0.4^{+0.5}_{-0.3}$
e_{3D}	$0.1^{+1.0}_{-0.1}$	$2.1^{+1.1}_{-0.2}$	$0.6^{+1.1}_{-0.5}$	$0.4^{+0.7}_{-0.3}$

Racine et al, AAPM 2015; Submitted to Medical Physics

Some clinical challenges in HDR Brachytherapy

- Catheter digitization is absolutely critical in the accurate delivery of the planned dose.
- On MR & US, precise catheter digitization is even more difficult than CT.
- Intra-user variability can be significant, especially with systems where the dwell positions are defined from the tip and therefore placement error propagates down the entire catheter.

EM Guidance can address

Real-time catheter tracking for high-dose-rate prostate brachytherapy using an electromagnetic 3D-guidance device: A preliminary performance study
Jun Zhou, Evelyn Sebastian, Victor Mangona, and Di Yan — **Med. Phys. 40 (2), February 2013**

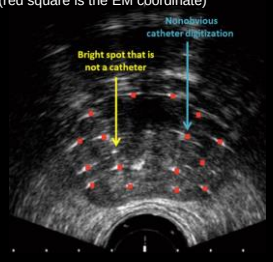
Electromagnetic tracking for catheter reconstruction in ultrasound-guided high-dose-rate brachytherapy of t — **Med. Phys. 41 (10), October 2014**
Shyam Bharat[1,*], Cynthia Kung[1], Ehsan Dehghan[1], Ananth Ravi[2], Niranjan Venugopal[2], Antonio Bonillas[1], Doug Stanton[1], Jochen Kruecker[1]
Brachytherapy 13 (2014) 640–650

Fast, automatic, and accurate catheter reconstruction in HDR brachytherapy using an electromagnetic 3D tracking system
Eric Poulin, Emmanuel Racine, Dirk Binnekamp, and Luc Beaulieu — **Med. Phys. 42 (3), March 2015**

A system to use electromagnetic tracking for the quality assurance of brachytherapy catheter digitization
Antonio L. Damato, Akila N. Viswanathan, Sarah M. Don, Jorgen L. Hansen, and Robert A. Cormack

EM Tracking in HDR Brachytherapy

- For US based planning (red square is the EM coordinate)



Bharat et al. Brachytherapy (2014)

Some clinical challenges in HDR Brachytherapy

- Catheter digitization is absolutely critical in the accurate delivery of the planned dose.
- On MR & US, precise catheter digitization is even more difficult than CT.
- Intra-user variability can be significant, especially with systems where the dwell positions are defined from the tip and therefore placement error propagates down the entire catheter.

EM Guidance can address

Real-time catheter tracking for high-dose-rate prostate brachytherapy using an electromagnetic 3D-guidance device: A preliminary performance study
Jun Zhou, Evelyn Sebastian, Victor Mangona, and Di Yan — **Med. Phys. 40 (2), February 2013**

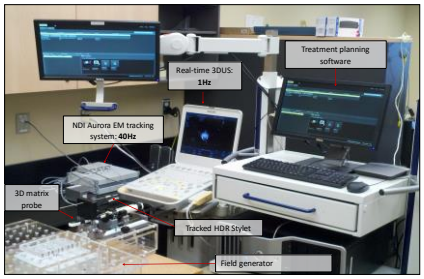
Electromagnetic tracking for catheter reconstruction in ultrasound-guided high-dose-rate brachytherapy of t — **Med. Phys. 41 (10), October 2014**
Shyam Bharat[1,*], Cynthia Kung[1], Ehsan Dehghan[1], Ananth Ravi[2], Niranjan Venugopal[2], Antonio Bonillas[1], Doug Stanton[1], Jochen Kruecker[1]
Brachytherapy 13 (2014) 640–650

Fast, automatic, and accurate catheter reconstruction in HDR brachytherapy using an electromagnetic 3D tracking system
Eric Poulin, Emmanuel Racine, Dirk Binnekamp, and Luc Beaulieu — **Med. Phys. 42 (3), March 2015**

A system to use electromagnetic tracking for the quality assurance of brachytherapy catheter digitization
Antonio L. Damato, Akila N. Viswanathan, Sarah M. Don, Jorgen L. Hansen, and Robert A. Cormack

Slide Courtesy of Luc Beaulieu (ABS 2016)

Real-time EM Tracking System



Slide Courtesy of Luc Beaulieu

Auto. Catheter/Applicator Channel Reconstruction

Fast, automatic, and accurate catheter reconstruction in HDR brachytherapy using an electromagnetic 3D tracking system

Eric Poulin and Emmanuel Racine

Département de physique, de génie physique et d'optique et Centre de recherche sur le cancer de l'Université Laval, Université Laval, Québec, Québec G1V 0A6, Canada and Département de radio-oncologie et Axe Oncologie du Centre de recherche du CHU de Québec, CHU de Québec, 11 Côte du Palais, Québec, Québec G1R 2J6, Canada

Dirk Verhaegen

Nucletron Operations Netherlands Solutions & Marketing, Philips Healthcare, Veenpluis 4-6, Best 5680 DA, The Netherlands Integrated Cancer

Luc Beaulieu

Département de physique, de génie physique et d'optique et Centre de recherche sur le cancer de l'Université Laval, Université Laval, Québec, Québec G1V 0A6, Canada and Département de radio-oncologie et Axe Oncologie du Centre de recherche du CHU de Québec, CHU de Québec, 11 Côte du Palais, Québec, Québec G1R 2J6, Canada

(Received 8 May 2014; revised 9 January 2015; accepted for publication 26 January 2015; published 18 February 2015)

Purpose: In high dose rate brachytherapy (HDR-B), current catheter reconstruction protocols are relatively slow and error prone. The purpose of this technical note is to evaluate the accuracy and the robustness of an electromagnetic (EM) tracking system for automated and real-time catheter reconstruction.

Methods: For this preclinical study, a total of ten catheters were inserted in gelatin phantoms with different trajectories. Catheters were reconstructed using a 18G biopsy needle, used as an EM stylet and equipped with a miniaturized sensor, and the second generation Aurora® Planar Field Generator from Northern Digital Inc. (NDI). The EM reconstructions were compared to a µCT and a CT with spatial resolution of 0.7 mm and 0.2°, respectively. Phantoms were also scanned using a µCT (GE Healthcare) and Philips Big Bore clinical computed tomography (CT) system with a spatial resolution of 89 µm and 2 mm, respectively. Reconstructions using the EM stylet were compared to µCT and CT. To assess the robustness of the EM reconstruction, five catheters were reconstructed twice and compared.

Results: Reconstruction time for one catheter was 10 s, leading to a total reconstruction time inferior to 5 min for a typical 17 catheter implant. When compared to the µCT, the mean EM tip identification error was 0.48 ± 0.29 mm while the CT error was 1.08 ± 0.67 mm. The mean 3D distance error was found to be 0.46 ± 0.33 mm and 1.08 ± 0.72 mm for the EM and CT, respectively. EM 3D catheter trajectories were found to be more accurate. A maximum difference of less than 0.6 mm was found between two successive EM reconstructions.

Conclusions: The EM reconstruction was found to be more accurate and precise than the conventional methods used for catheter reconstruction in HDR-B. This approach can be applied to any type of catheters and applicators. © 2015 American Association of Physicists in Medicine. [http://dx.doi.org/10.1118/1.4908011]

- EM reconstructions at 40 Hz
- µCT reconstruction (GE) at 89 µm (reference)
- CT reconstructions (Philips BigBore) at 2 mm
- Reconstructions using the EM stylet were compared to µCT and CT (3D distances used; tips as reference).
- To assess the robustness of the EM reconstruction, by reconstructing catheters multiple times.

Medical Physics 2015;42(3):1227–32.

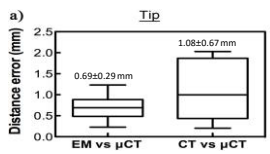
Slide Courtesy of Luc Beaulieu

Auto. Channel reconstruction

10 catheters were inserted in gelatin phantoms with different trajectories.

Slide Courtesy of Luc Beaulieu

Auto. Channel reconstruction



US vs EM
2.73±2.28 mm

Unpaired Student t-test show statistically significance difference

Poulin et al, Medical Physics 2015;42(3):1227–32.

* Comparison between EM vs US-only reconstruction, see poster # **2016-A-418-ABS**

Some clinical challenges in HDR Brachytherapy

- Catheter digitization is absolutely critical in the accurate delivery of the planned dose.
- On MR & US, precise catheter digitization is even more difficult than CT.
- Intra-user variability can be significant, especially with systems where the dwell positions are defined from the tip and therefore placement error propagates down the entire catheter.

EM Guidance can address

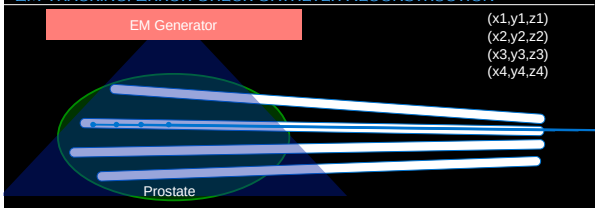
Real-time catheter tracking for high-dose-rate prostate brachytherapy using an electromagnetic 3D-guidance device: A preliminary performance study
Jun Zhou, Evelyn Sebastian, Victor Mangona, and Di Yan — **Med. Phys. 40 (2), February 2013**

Electromagnetic tracking for catheter reconstruction in ultrasound-guided high-dose-rate brachytherapy of t — **Med. Phys. 41 (10), October 2014**
Shyam Bharat[1,*], Cynthia Kung[1], Ehsan Dehghan[1], Ananth Ravi[2], Niranjan Venugopal[2], Antonio Bonillas[1], Doug Stanton[1], Jochen Kruecker[1]
Brachytherapy 13 (2014) 640–650

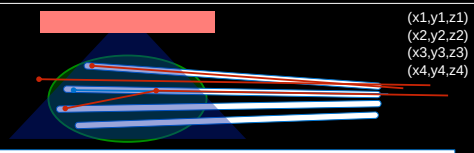
Fast, automatic, and accurate catheter reconstruction in HDR brachytherapy using an electromagnetic 3D tracking system
Eric Poulin, Emmanuel Racine, Dirk Binnekamp, and Luc Beaulieu — **Med. Phys. 42 (3), March 2015**

A system to use electromagnetic tracking for the quality assurance of brachytherapy catheter digitization
Antonio L. Damato, Akila N. Viswanathan, Sarah M. Don, Jorgen L. Hansen, and Robert A. Cormack

EM Tracking: Error Check Catheter Reconstruction



EM Tracking: Automatic Catheter Reconstruction



3 main errors in catheter digitization

Damato et al. MedPhys (2014)

Summary: EM Tracking in Brachytherapy

HDR Brachytherapy

- Depending on setup, full digitization can be done on the order of seconds to several minutes.
- Can be used to QA a manually generated catheter geometry by systematically evaluating differences in geometry
- Can be used to generate the catheter geometry.
- Calibration to US/CT/MR planning images is critical!

Seed implant brachytherapy

- Monitor seed placement
- If able to integrate with a treatment planning system,
  - real time update of implanted dosimetry,
  - can adapt plan to accommodate mis-placement of seeds
- Real-time *adaptive* brachytherapy

Cautions

- Have to be careful with setup because metal may induce interference and therefore uncertainties in measurements.
- Precision is on the order of 1 mm (Field generator specs.)
- Accuracy highly dependent on calibration.

Workflow Element	Current Practice	Robotic Brachy
Imaging (placement)	US for real-time needle location feedback	US/MR/CT imaging using stereotactic registration
Needle orientation configuration	Template for needle placement precision	Robot motor control system with 6+ d.o.f.
	All needles are parallel	Can allow for non-parallel needle geometries
	Difficult to avoid normal structures (penile bulb)	Can fully avoid puncture of penile bulb
Source position optimization (PPI)	Template: relatively small number possible	No template: many more possibilities
Needle insertion/retraction; seed deposition	Physician	Physician or robot motor control
Seed location verification	Post-implant CT (Intra-op CT)	Robot maintains stereotactic position info. Post-implant CT.
	Dual source type implants difficult	Stereotactic info makes feasible
Extend brachy to new anatomical sites	Need cavity-based, US-imaging accessible, or naked-eye visible	MR or CT allows for access to any area of the body

A robot will be truly autonomous
when you instruct it to go to work,
and it decides to go to the beach instead.

- Brad Templeton

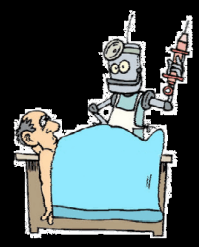


Image credit: www.patrickweb.com/wordpress/2010/11/21/2008

Recent Technology Innovations in Prostate Brachytherapy

J. Adam M. Cunha, Ph.D.
University of California (UCSF)
San Francisco, CA

EM Guided WorkFlow

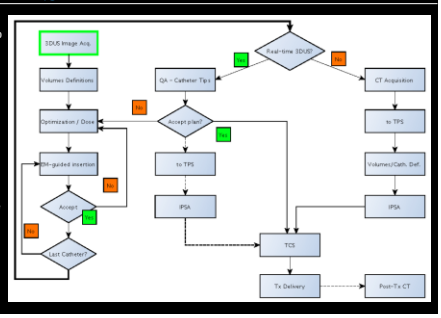
Guidance is always on – no needle searching

Catheter reconstruction
- On the fly
- Link to dose calculation and inverse planning
- Not a bottleneck anymore

Streamline interface and workflow: < 1h procedure?

Workflow is same for whole gland and focal therapy

Tips position accuracy and comparison to CT

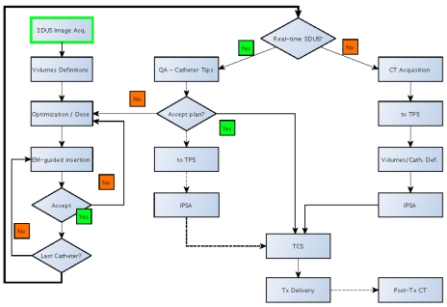


Slide Courtesy of Luc Beaulieu

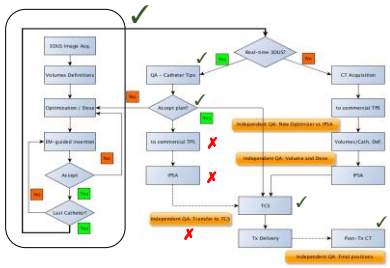
Procedure time

Running time (min)	
5-15	• Image acquisition: 1 sec • *Contouring: 5-15 min*
10-20	• Planning: 7.6±2.5 sec ➔ more time reviewing/rerun!
26-36	• Insertion: - *27.6±6.7 sec/catheter or needle on phantom* - *≈ 60 sec/catheter or needle* expected for actual patient
30-40	• Catheter/Tip Reconstruction: - First one included with insertion time (free!) - Additional: 10.5±3.1 sec/catheter or needle

Complete procedure under 1 hour potentially feasible



Conclusion - Workflow



Slide Courtesy of Luc Beaulieu