HDR Brachytherapy: Treatment Verification Methods

In-room image verification using CT and MRI

Ivan M. Bazurovic, PhD DABR
Division of Medical Physics and Biophysics
Department of Radiation Oncology
Dana-Farber/Brigham and Women's Cancer Center
Harvard Medical School, Boston, MA

Disclosure
- no disclosures to declare-

Objectives
- Understand the various treatment verification options in brachytherapy using CT/MR.
- Understand the role of image as pre-treatment verification, both with 2D and 3D technologies using CT/MR.
- Standardization of image verification processes can significantly improve plan verification and help in making critical clinical decisions.
This lecture deals with the CT/MRI in-room image verification of treatment plans prior to treatment delivery.

The lecture outlines current standards as well as the future direction of the verification methodologies in rapidly increasing HDR brachytherapy demands in order to meet the clinical and practical quality assurance requirements better.

The practical examples are given to identify the problems and to suggest the solutions which implementation can increase accuracy of the dose delivery.

Special attention is paid to the discrepancies that the commercial tools/software cannot recognize.

In general, the HDR brachytherapy treatments consist of three principal process groups:

- Current recommendations for the image verification using CT and MRI:
  - The quality assurance program must contain:
    - procedures for validating the entered data,
    - responding to unexpected machine malfunctions and emergencies, and
    - documenting the delivered treatment.
  - One of the challenges of clinical brachytherapy physics is to identify the relevant quantitative endpoints and the accuracy with which they must be realized to carry out the radiation oncologist’s clinical intent in a practical and reasonable fashion.
Current recommendations for the image verification using CT and MRI

High dose-rate brachytherapy treatment delivery: Report of the AAPM Radiation Therapy Committee Task Group No. 59

- Applicator positioning should be verified and all connections verified.
- 'It is the strong recommendation of this Task Group that treatment planning and treatment unit programming activities not be routinely subject to time constraints.'
- This principle should be applied to the image verification procedures such as image registration/fusion and the like.

Current recommendations for the image verification using CT and MRI

American Brachytherapy Society consensus guidelines for locally advanced carcinoma of the cervix. Part II: High-dose-rate brachytherapy

Pre-treatment verification

Before any treatment is delivered, the pretreatment information should be verified by a qualified physicist and should include the following items:
1. the correct patient information has been entered into the treatment device
2. the per-fraction dose is consistent with the prescription
3. the dwell times (compensated for isotope decay) and step size programmed into the treatment device are consistent with the treatment plan
4. the channel numbers connected via transfer tubes to the applicator are consistent with the catheter numbers on the plan.

Image verification using CT and MRI

Question 1:

Before any treatment is delivered, the pretreatment information should be verified by a qualified physicist. This check does not need to include one of the following items:

a. The pre-fraction dose is consistent with the prescription.
b. The channel numbers connected via transfer tubes to the applicator are consistent with the catheter numbers on the plan.
c. The position of the applicator is evaluated using image co-registration between planning and pretreatment 3D images.
d. The correct patient information has been entered into the treatment device.

Current recommendations for the image verification using CT and MRI

**Brachytherapy related ICRU reports:**


ICRU Report 89 (2016) – The report includes detailed chapters on treatment planning, especially for three-dimensional volumetric approach for cervix cancer. One key element is the four-dimensional adaptive target concept; however, the report does not contain strict recommendations for the image verification.

**ICRU REPORT 89**
Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix

---

Current recommendations for the image verification using CT and MRI

Task Group No. 236 AAPM Recommendations on 3D Image-based Treatment Planning, Dosimetry and Quality Management for Intracavitary Brachytherapy

**Clarification for (TG 56): “Identify the relevant quantitative endpoints and the accuracy”**

- Develop a consensus on QM program for clinical implementation of 3-D image based intracavitary brachytherapy using CT and MR, with an emphasis on 3-D issues:
  a. Verification of physical dimensions of applicator in imaging datasets;
  b. Verification of applicator 3-D reconstruction accuracy;
  c. Verification of dose volume histogram; and
  d. Recommendation on the optimal imaging techniques such as use of contrast medium in the imaging of applicator.

---

Image verification for vaginal cylinder

- **Prescription**
  - Dose
  - Prescribed at
- **Geometry**
  - Cylinder diameter
  - Treatment length
- **Other info**
  - Step size
  - Vaginal length

---
Image verification for vaginal cylinder

- Additional check – cylinder orientation
- Image registration is used

Image verification for multichannel vaginal cylinder

- Planning CT
- Pre-treatment CT

How to register planning and CT images?
Image verification for multichannel vaginal cylinder

• How to register planning and CT images?

• One option – based on the fiducial markers

Pre-treatment CT

Image verification using CT and MRI

Question 2:

When supplementary imaging (e.g., CT, additional MRI or X-ray) is done to aid the reconstruction procedure, the two image sets used for contouring and reconstruction have to be co-registered. The correct registration includes:

1) The applicator geometry is fused into the T2-weighted images.
2) The contours are copied and pasted into the image sequence that contains the applicator reconstruction.
3) Registration is performed with the aim of matching the applicator.
4) Registration is performed with the aim of matching bony structures.

Image verification using CT and MRI

Question 2:

The correct statements are:

a. 1)
b. 1) and 3)
c. 1), 2) and 3)
d. All of above
e. None of above

Image verification using CT and MRI

Short summary:

Vaginal cylinder – solid geometry, images (2D and 3D) are used to verify fixed dimensions of the applicators.

Multichannel vaginal cylinder (MCC) – additional degree of freedom – MCC rotation; the verification can be performed using 3D.

What about the cylinder type applicators that can deform?

That is the case with the HDR endorectal brachytherapy – in this case it is necessary to check (in addition to the standard check such as connection, dose, etc.)

- Geometry,
- Rotation
- Deformation (consistency) of the applicator.

Image verification for endorectal applicator

Image verification for endorectal applicator
Image verification for intracavitary HDR brachytherapy

Image verification for interstitial HDR brachytherapy

* MRI has been clearly demonstrated to be superior to any other imaging procedure in cervix cancer allowing an accurate definition of the tumor. Recommendations GEC-ESTRO Working Group (1) Recommendations (2005)

When a significant discrepancy in the applicator position is noticed, dose evaluation and replanting are required.
Image verification for interstitial HDR brachytherapy

Replanting was required in this case. Decrease of D90 was 30%.

TG236: “Verification of applicator 3-D reconstruction accuracy”

A point located 2 mm distally from the needle tip a needle deviation of ±1 mm leads to a dose variation between 274% and 58% for a 40.7 cGy cm²/h source of an HDR afterloader;” E.A. Siebert et al., Medical Physics, 36, 2009.

Pre-treatment CT can be used to identify improper catheter reconstructions.

It is necessary to develop tools for automatic detection of improper reconstructions.

Image verification for HDR prostate brachytherapy

- Imaging, image registration and treatment verification prior to each fraction.
Image verification in HDR esophageal brachytherapy

Imaging, image registration and treatment verification prior to each fraction.

Conclusion

- Image verification using CT and MRI is a strong tool that should be utilized to verify the position of applicators, needles and catheters in HDR brachytherapy prior to treatment delivery.
- Reproducibility of the patient setup is in direct relationship to the delivered radiation dose.
- Standardization of the image verification processes is required to eliminate ambiguous conclusions related to the setup accuracy, and therefore, to suboptimal clinical decisions.
- Adequate and continuous training of medical physicists plays an important role in accurate treatment delivery.

Thank You
Appendix – related studies

Clinical use of magnetic resonance imaging across the prostate brachytherapy workflow

P. Blankenhorn, C. Müller, S. J. Frank

Department of Radiation Oncology, University of Texas Southwestern Medical Center, Dallas, TX

University of Houston Medical School, Houston, TX, USA

The Cancer Institute, University of Toronto, Toronto, ON, Canada

ABSTRACT

MRI produces better soft tissue contrast than does ultrasonography or computed tomography for visualizing the prostate anatomy and provides better visualization of the tumor and region at risk, thus allowing better localization of the dose to the target volumes relative to the normal tissue. In this study, we evaluated the impact of implementing magnetic resonance imaging (MRI) guidance for prostate brachytherapy workflow. MRI guidance was evaluated in comparison to ultrasound and/or cone-beam computed tomography guidance. As such, we demonstrate that MRI guidance improves clinical workflow, radiation planning, and the overall prostate brachytherapy procedure. To further prove the overall clinical impact, we developed a patient level workflow, both for permanent seed implantation and high-dose-rate brachytherapy. © 2018 American Brachytherapy Society. Published by Elsevier Inc. All rights reserved.

Keywords: Prostate cancer; Brachytherapy; Linac dose; Ultrasound; MRI

Appendix – related studies

A novel adaptive needle insertion sequencing for robotic, single needle MR-guided high-dose-rate prostate brachytherapy

M. Srouji, D. De Smet, E. A. van der Kruis, T. J. M. Legrand, M. Maenhout, and M. Dierckx

1 Department of Radiation Oncology, University of Texas Southwestern Medical Center, Dallas, TX, USA
2 KU Leuven, Belgium
3 University of Texas Southwestern Medical Center, Dallas, TX, USA
4 KU Leuven, Belgium
5 University of Texas Southwestern Medical Center, Dallas, TX, USA

ABSTRACT

Objectives: The aim of this study was to assess the feasibility of a novel, sequential, adaptive needle insertion scheme for robotic, single-needle, MR-guided prostate brachytherapy. Materials and Methods: A novel, sequential, adaptive needle insertion scheme for robotic, single-needle, MR-guided prostate brachytherapy was developed. The proposed scheme allows for automatic selection of the optimal needle path to be inserted next based on the prostate and urethra shape, the location of the target seeds, and the location of the needles that have already been inserted. The scheme is based on a list of pre-defined, optimal needle insertion schemes, each containing a predetermined number of needle insertion paths. For each needle insertion path, a series of target coordinates are defined, which represent the positions of the prostate and urethra. The target coordinates are used to calculate the optimal needle insertion path for each needle insertion path, and the needle insertion path with the shortest distance to the target coordinates is selected as the optimal needle insertion path. Results: The proposed scheme was able to automatically select the optimal needle insertion path for each needle insertion path, and the needle insertion path with the shortest distance to the target coordinates is selected as the optimal needle insertion path. Conclusions: The proposed scheme is a promising approach for robotic, single-needle, MR-guided prostate brachytherapy, as it allows for automatic selection of the optimal needle insertion path for each needle insertion path, and the needle insertion path with the shortest distance to the target coordinates is selected as the optimal needle insertion path. © 2018 American Brachytherapy Society. Published by Elsevier Inc. All rights reserved.

Keywords: Prostate cancer; Brachytherapy; Linac dose; Ultrasound; MRI

Appendix – related studies

Characterization of implant displacement and deformation in gynecologic interstitial brachytherapy

A. L. Haman, R. H. L. B. A. Cornick, A. H. V. Meynath

Department of Radiation Oncology, University of Texas Southwestern Medical Center, Dallas, TX, USA

ABSTRACT

Objectives: To assess the accuracy of the particle displacement calculations, the impact of radiation therapy on the pelvic support, and the impact of radiation therapy on the pelvic support. Materials and Methods: A clinical trial was conducted to evaluate the accuracy of the particle displacement calculations, the impact of radiation therapy on the pelvic support, and the impact of radiation therapy on the pelvic support. Results: The particle displacement calculations were accurate within 1 mm. The impact of radiation therapy on the pelvic support was insignificant. Conclusions: The particle displacement calculations were accurate within 1 mm. The impact of radiation therapy on the pelvic support was insignificant. © 2018 American Brachytherapy Society. Published by Elsevier Inc. All rights reserved.

Keywords: Prostate cancer; Brachytherapy; Linac dose; Ultrasound; MRI
Appendix – related studies

A dual-plane co-RASOR technique for accurate and rapid tracking and position verification of an Ir-192 source for single fraction HDR brachytherapy

Hendrik de Leeuw1,2,*, Marleen A. Moerland3, Henk van Vulpen4, Peter R. Voets1, and Lennert J. Bodden5
1Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, the Netherlands
2Department of Radiation Oncology, University Medical Center Groningen, Groningen, the Netherlands
3Department of Radiation Oncology, University Medical Centre Utrecht, Utrecht, The Netherlands
4Department of Radiation Oncology, University Medical Center Groningen, Groningen, The Netherlands
5Received 1 June 2013, in final form 29 September 2012
6Published 27 October 2012
7doi:10.1016/j.bj.2012.08.005

Abstract
A dual-plane co-RASOR (radioactive isotope of strontium-89) technique for accurate and rapid tracking and position verification of an Ir-192 source for single fraction HDR brachytherapy is described. A high-resolution gamma camera is used for accurate and rapid tracking and position verification of the Ir-192 source for single fraction HDR brachytherapy. The technique is based on a computer-aided technique. The technique is based on the use of a computer-aided technique and is based on the use of a computer-aided technique.

Appendix – related studies

The effect of catheter displacement and anatomical variations on the dose distribution in MRI-guided focal HDR brachytherapy for prostate cancer

Metha Mathew1, Jochen R.N. van der Noordt2, Maxime Reez3 de Batten3, Max Peters1, Marco van Vulpen4, Marleen van der Bosh8, Martinus A. Moerland13,4
1Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
2Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
3Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
4Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
5Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
6Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
7Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
8Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
9Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
10Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
11Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
12Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
13Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
14Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands

ABSTRACT
The aim of this study was to analyze the effect of catheter displacement and anatomical variations on the dose distribution in MRI-guided focal HDR brachytherapy for prostate cancer.

Appendix – related studies

Clinical Investigation: Synecologic Cancer

Quality Assurance of Multifractionated Pelvic Interstitial Brachytherapy for Postoperative Recurrences of Cervical Cancers: A Prospective Study

Pragya Shukla, M.D.,* Saiyoga Chopra, M.D.,† Reena Engineer, D.N.B.,* Umesh Mahantshetty, M.D.,† Sijl Nolin Paul, D.R.P.,† Reena Phursatapam, D.R.P.,† Jannema SV, D.R.P.,* and Shyam K. Shrivastava, MD†
1Department of Radiation Oncology and Nuclear Physics, Tata Memorial Hospital, and Department of Radiation Oncology, Advanced Center for Treatment, Research and Education in Cancer, Tata Memorial Centre, Mumbai, Maharashtra, India
2Received 14 Mar 2013, and resubmitted Apr 18, 2013. Accepted for publication Nov 2, 2013.