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HDR Brachytherapy: Treatment Verification Methods

In-room image verification using CT and MRI

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Disclosure
- no disclosures to declare-

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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.

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Image verification using CT and MRI

This lecture deals with the CT/MRI in-room image verification of treatment plans prior to treatment delivery.

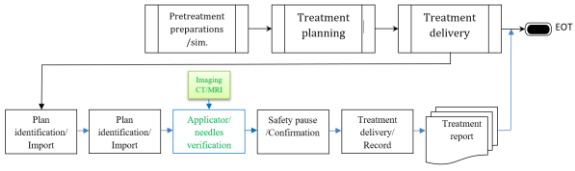
The lecture outlines current standards as well as the future direction of the verification methodologies in rapidly increasing HDR brachytherapy demands in order to meet the clinical and practical quality assurance requirements better.

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.

HDR Brachytherapy process map

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



Current recommendations for the image verification using CT and MRI

Code of practice for brachytherapy physics: Report of the AAPM Radiation Therapy Committee Task Group No. 56

- 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

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BRACHYTHERAPY

Brachytherapy 11 (2012) 47–52

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 pre-treatment 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 catheters 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.

Reference: Viswanathan, A.N. et al., 2012. American Brachytherapy Society consensus guidelines for locally advanced carcinoma of the cervix. Part II: High-dose-rate brachytherapy. Brachytherapy, 11(1), pp.47–52.

Current recommendations for the image verification using CT and MRI

Brachytherapy related ICRU reports:

ICRU Report 38 (1985) – Dose and volume specification and reporting for GYN Intracavitary Brachytherapy.

ICRU Report 58 (1997) – Guidelines related to the dose specifications and reporting for Interstitial Brachytherapy.

ICRU Report 89 (2016) – The report includes detailed chapters on treatment planning, especially for three-dimensional volumetric approach for cervix caner. 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


Dana-Farber/Brigham and Women's Cancer Center · Department of Radiation Oncology

HDR Afterloader Brachytherapy Written Directive

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

Image verification for vaginal cylinder

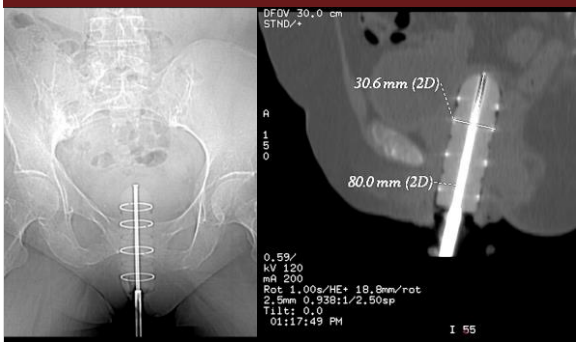
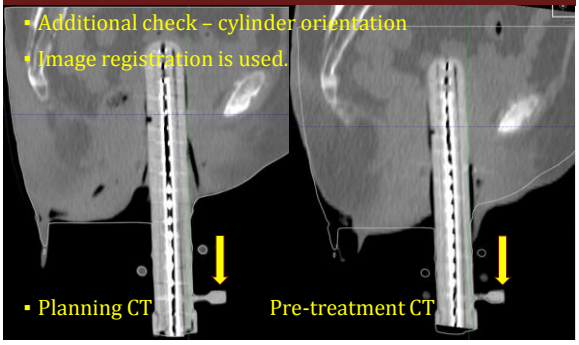


Image verification for multichannel vaginal cylinder

- Additional check – cylinder orientation
- Image registration is used.



- Planning CT
- Pre-treatment CT

Image verification for multichannel vaginal cylinder

- How to register planning and CT images?

Planning CT

Image verification for multichannel vaginal cylinder

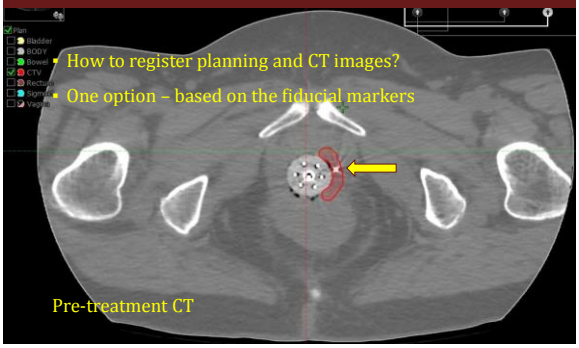


Image verification using CT and MRI

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

Reference: Hellebust, T.P. et al., 2010. Recommendations from Gynaecological (GYN) GEC-ESTRO Working Group: Considerations and pitfalls in commissioning and applicator reconstruction in 3D image-based treatment planning of cervix cancer brachytherapy. Radiotherapy and Oncology, 96(2), pp.153–160

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

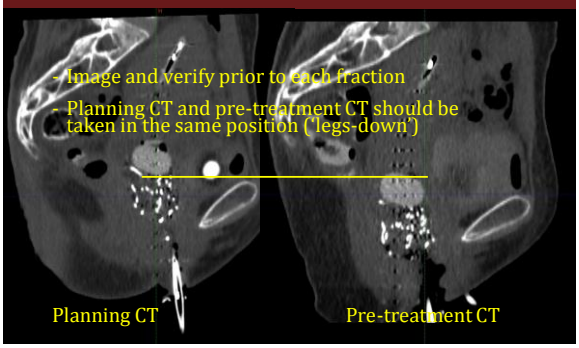
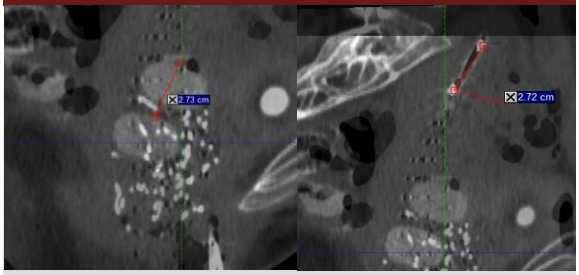
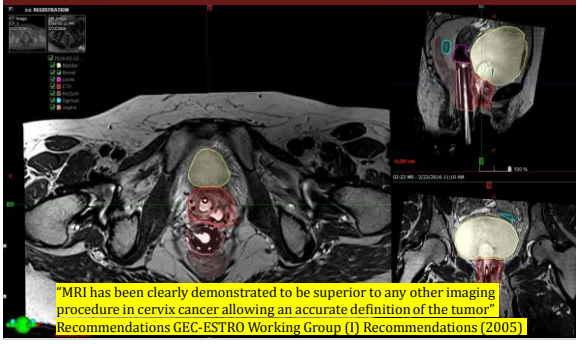


Image verification for intracavitary HDR brachytherapy



- When a significant discrepancy in the applicator position is noticed, dose evaluation and replanting are required.

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 (I) Recommendations (2005)

Image verification for interstitial HDR brachytherapy

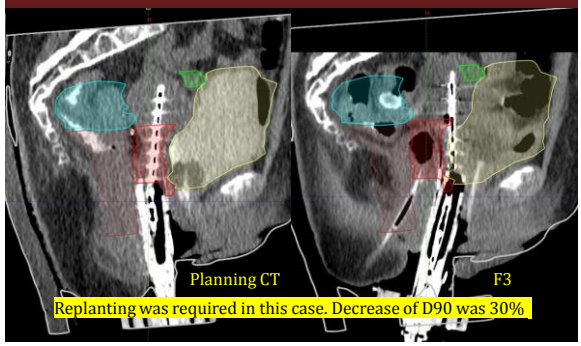


Image verification for interstitial HDR brachytherapy

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, ' F.A. Siebert et al., Medical Physics, 36, 2009.

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

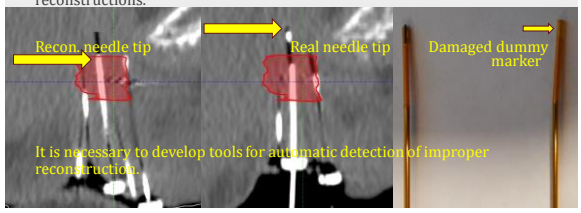
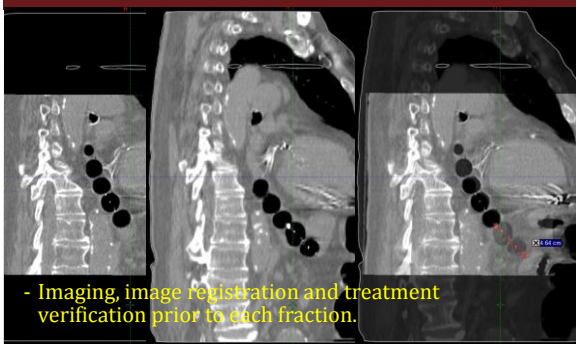


Image verification for HDR prostate brachytherapy

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.

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Thank You

Appendix – related studies

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BRACHYTHERAPY

Brachytherapy ■ (2017) ■

Clinical use of magnetic resonance imaging across the prostate brachytherapy workflow

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ABSTRACT MRI produces better soft tissue contrast than does ultrasonography or computed tomography for visualizing male pelvic anatomy and prostate cancer. Better visualization of the tumor and organs at risk could allow better conformation of the dose to the target volumes while at the same time minimizing the dose to critical structures and the associated toxicity. Although the use of MRI for prostate brachytherapy would theoretically result in an improved therapeutic ratio, its implementation been slow, mostly because of technical challenges. In this review, we describe the potential role of MRI at different steps in the treatment workflow for prostate brachytherapy: for patient selection, treatment planning, in the operating room, or for postimplant assessment. We further present the current clinical experience with MRI-guided prostate brachytherapy, both for permanent seed implantation and high–dose-rate brachytherapy. © 2016 American Brachytherapy Society. Published by Elsevier Inc. All rights reserved.

Keywords: Prostate cancer; Brachytherapy; Low-dose rate; High-dose rate; MRI

Appendix – related studies

IOP Publishing | Institute of Physics and Engineering in Medicine — Physics in Medicine & Biology

Phys. Med. Biol. 62 (2017) 4031–4045 — https://doi.org/10.1088/1361-6560/aa664b

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

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Appendix – related studies

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BRACHYTHERAPY

Brachytherapy 13 (2014) 100–109

Characterization of implant displacement and deformation in gynecologic interstitial brachytherapy

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Department of Radiation Oncology, Brigham and Women's Hospital and Dana-Farber Cancer Institute, Boston, MA

ABSTRACT **PURPOSE:** To determine the uncertainties in implant position during multifraction gynecologic interstitial brachytherapy, we analyzed the interfraction displacements and deformations of gynecologic interstitial implants.
METHODS AND MATERIALS: Fourteen gynecologic patients treated with multifraction high-dose-rate interstitial brachytherapy received two CT scans each at the time of implantation and 48–72 h later. Rigid fusions on the pubic symphysis were performed. This analysis included catheter shifts in the cranial (CR), caudal (CA), anterior, posterior, left, and right directions; template shifts; the change in the catheter length measured along the path from catheter tip to catheter connector (offset); the change in relative distances between catheters (deformations); and changes in rectum and bladder D_{2cc} and tumor D_{90}.
RESULTS: Of the 198 catheters analyzed, the number of catheter shifts (%) and mean ± standard deviation were 43% CA (5.0 ± 2.0 mm), 22% CR (7.9 ± 4.0 mm), 14% anterior (6.3 ± 2.1 mm), 48% posterior (8.7 ± 3.1 mm), 7% left (4.8 ± 0.4 mm), and 9% right (5.4 ± 0.9 mm). Catheter offsets were 3% CA (7.2 ± 6.3 mm) and 11% CR (6.1 ± 2.6 mm). Template shifts were 43% CA (5.2 ± 1.6 mm) and 14% CR (6.6 ± 4.0 mm). Deformations were 10 shrinkages (4.7 ± 0.9 mm) and 32 expansions (4.7 ± 0.5 mm). Dosimetric changes were 5.2% ± 10.8% for rectum D_{2cc}, −1.1% ± 18.5% for bladder D_{2cc}, and −5.1% ± 6.7% for tumor D_{90}.
CONCLUSIONS: On average, less than 1 cm displacements and deformations of the implant occurred over the course of treatment. Proper quality assurance methodologies should be in place to detect shifts that can potentially result in inadvertent insertion into normal tissue. © 2014 American Brachytherapy Society. Published by Elsevier Inc. All rights reserved.

Keywords: Brachytherapy; Gynecologic; Interstitial; Displacement; Uncertainty; Catheter

Appendix – related studies

IOP Publishing
Phys. Med. Biol. 58 (2013) 7829–7839
Physics in Medicine and Biology
doi:10.1088/0031-9155/58/21/7829

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

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Online at stacks.iop.org/PMB/58/7829

Abstract
Effective high-dose-rate (HDR) treatment requires accurate and independent treatment verification to ensure that the treatment proceeds as prescribed, in particular if a high dose is given, as in single fraction therapy. Contrary to CT imaging and fluoroscopy, MR imaging provides high soft tissue contrast. Conventional MR techniques, however, do not offer the temporal resolution in combination with the 3D-spatial resolution required for accurate brachytherapy source localization. We have developed an MR imaging method (center-

Appendix – related studies

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Brachytherapy ■ (2017) ■
BRACHYTHERAPY

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

Metha Maenhout[1], Jochem R.N. van der Voort van Zyp[1], Maxence Borot de Battisti[1], Max Peters[1], Marco van Vulpen[1], Maurice van den Bosch[2], Marinus A. Moerland[1,*]
[1]Department of Radiation Oncology, University Medical Center Utrecht, Utrecht, The Netherlands
[2]Department of Radiology, University Medical Center Utrecht, Utrecht, The Netherlands

ABSTRACT **PURPOSE:** The aim of this study was to analyze the effect of catheter displacement and anatomical variations of prostate and organs at risk on dose distribution in MRI-guided 19 Gy single fraction focal high-dose-rate brachytherapy (HDR-BT) of the prostate.

Appendix – related studies

International Journal of Radiation Oncology biology ● physics
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Clinical Investigation: Gynecologic Cancer

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

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