AAPM 2017 JUL 30–AUG 3
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SAM: HDR Brachytherapy: Treatment Verification Methods

In-Room Treatment Verification Using Film and CBCT

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Role of imaging in modern brachytherapy

- Application insertion
- Planning
- ***Treatment Verification***

} Image-guided brachytherapy (IGBT)

- Applicator design
- Facilitate real-time dosimetry
- Dose summation
- Functional imaging

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Objectives

- To describe current applications of Film/Fluoro and CBCT(kV) in brachytherapy, especially as it relates to in-room treatment verification

- We have time for the “With What” and “For What”, but not for the “How”

FILM/Fluoro: With what?

- Standard simulator
- Flat panel detector
- (just film) Radiochromic film
- OR-based X-ray unit
- AccuBoost® (mammographic equipment)
- C-arm

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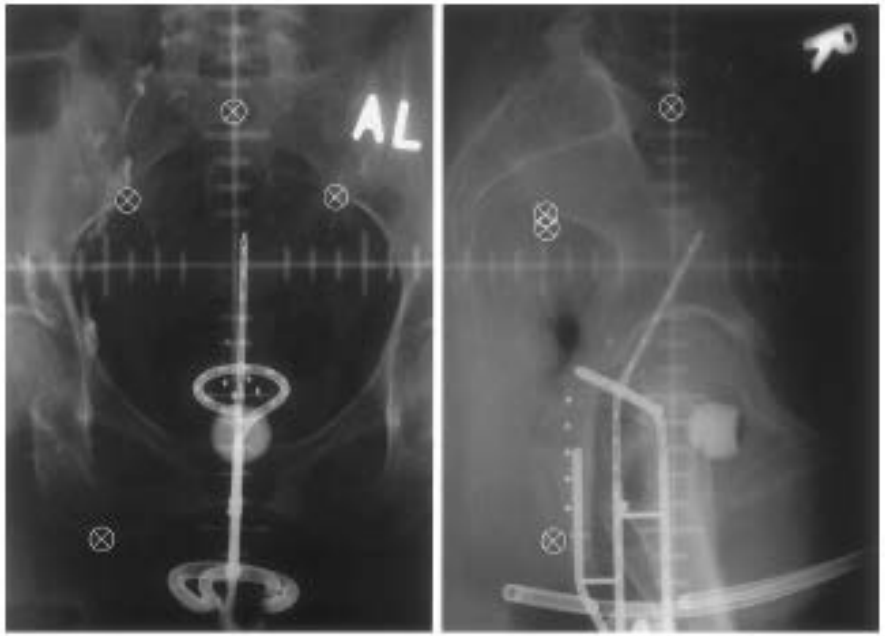
FILM/Fluoro: For What?

- LDR/HDR GYN:
  - Applicator insertion
  - Planning
    - Orthogonal
    - Semi-orthogonal planning with C-arm with/without jig
  - Pre-TX verification
- LDR prostate:
  - Needle loading by 3rd party
  - Post implant film verification
- HDR breast
  - IGBT with AccuBoost

- More recent reported uses:
  - Real time HDR TX verification with modified C-arm fluoroscopy (2016)
  - Pre-TX Catheter verification for HDR prostate (2017)
  - Guidance for free-hand needle placement in HDR GYN (2017)

FILM: 2D Planning GYN + (Potential refilming for TX verification)



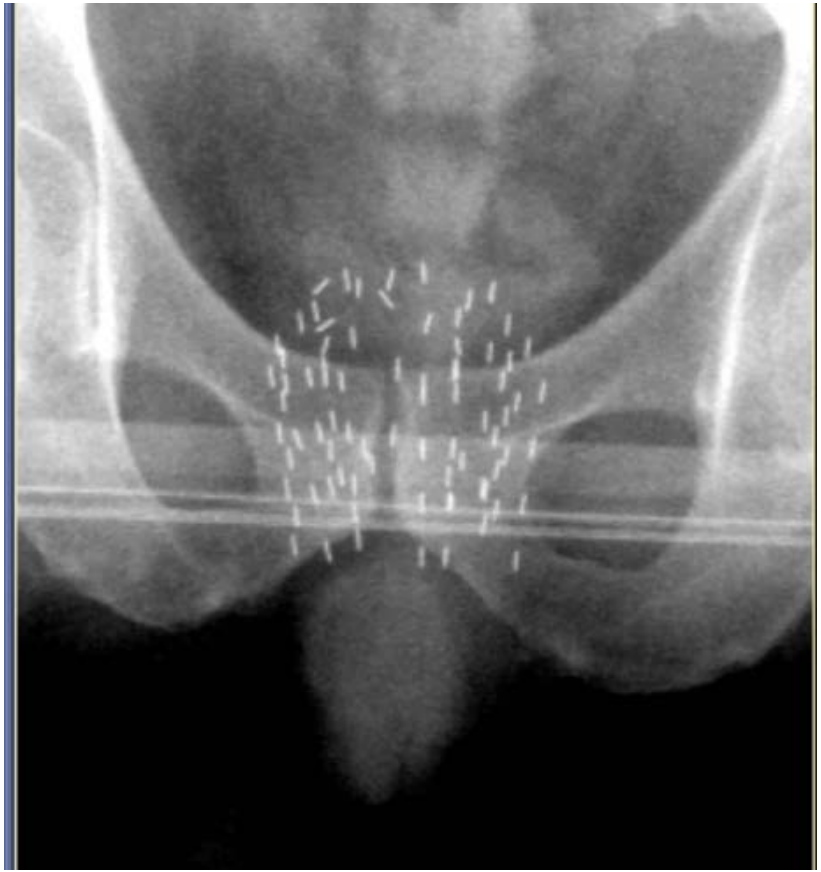
(a) (b)

Fig. 1. The anatomical reference points 1, 2, 3, and 4 on the first set of simulation films for a patient treated with ring and tandem applicator: (a) AP film; and (b) Right Lateral film.

FILM: LDR Prostate – TX verification of Implant

I-125 AgX100 Seed Prostate Implant Radiograph

Usually using x-ray unit in OR



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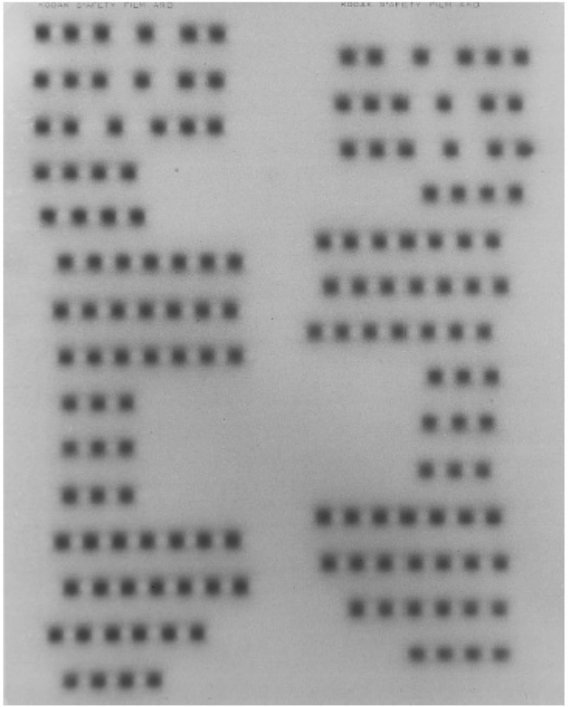
FILM: LDR prostate 3rd party loaded sterile needles + autoradiograph



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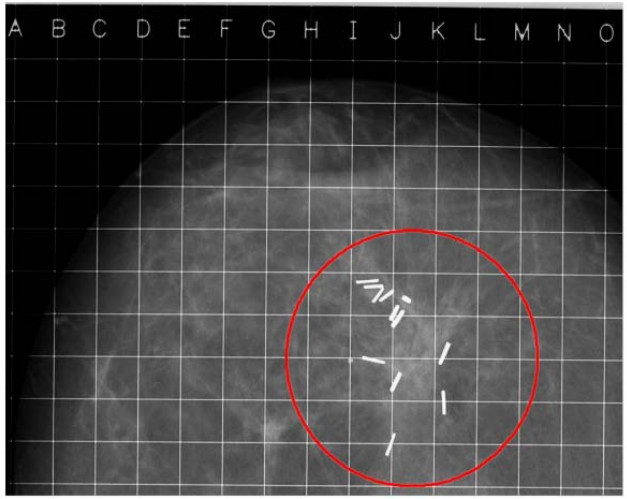
FILM: HDR Breast Boost (AccuBoost®)

AccuBoost

Applicator Selection



Tumor bed with 1 cm margin
6 cm Round Applicator

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From J Hiatt, Non-invasive Image-guided Breast Brachytherapy, AAPM 2015

FILM: HDR prostate

Clinical Application of Pre-Treatment Image Verification of Catheter Positions for HDR Prostate Brachytherapy

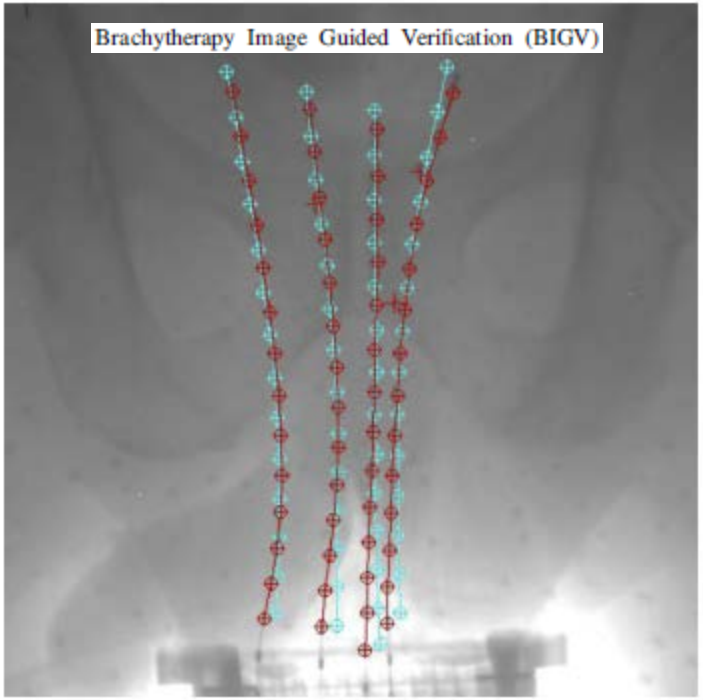
Ryan L. Smith, MAppSc, Annette Haworth, PhD, Max Hanlon, BSc, Bronwyn Matheson, MD, Jeremy Millar, MD, Vanessa Panettieri, PhD, Rick Franich, PhD

PO128

Materials and Methods: Pre-treatment imaging was performed for 28 treatment fractions, (2 fractions per patient) with the positions of the implanted catheters at each treatment fraction verified using the BIGV system. This system which consists of a flat panel detector (FPD) embedded into the brachytherapy treatment couch and a ceiling suspended x-ray device. The patient was setup on the treatment couch and aligned above the sensitive region of the FPD. Radio-opaque x-ray markers were inserted into the plastic proguide catheters in order to verify the positions relative to previously implanted gold prostate fiducial markers. The ceiling suspended x-ray system was positioned above the patient and an anterior-posterior (A-P) x-ray image was acquired with the FPD. The gold prostate fiducial markers were identified and registered with the markers identified in the treatment plan. A comparison of planned and measured catheter positions was then performed relative to the prostate. Catheter tip positions were compared and the agreement of the catheter path through the prostate region was evaluated for all catheters with inserted x-ray markers. Observed catheter displacements at treatment were re-created on the treatment plan to assess any dosimetric impact.

Conclusions: Pre-treatment imaging has been performed to verify catheter positions, with the patient in the treatment position, immediately prior to treatment delivery. The measured catheter displacements observed for fraction 1 were on average greater than fraction 2, and suggests the rate of perineum swelling is important and may result in a deviated dose distribution. The BIGV system which enables direct comparison of planned catheter positions with measured positions, immediately prior to treatment, permit the introduction of adaptive planning techniques in HDR prostate brachytherapy.

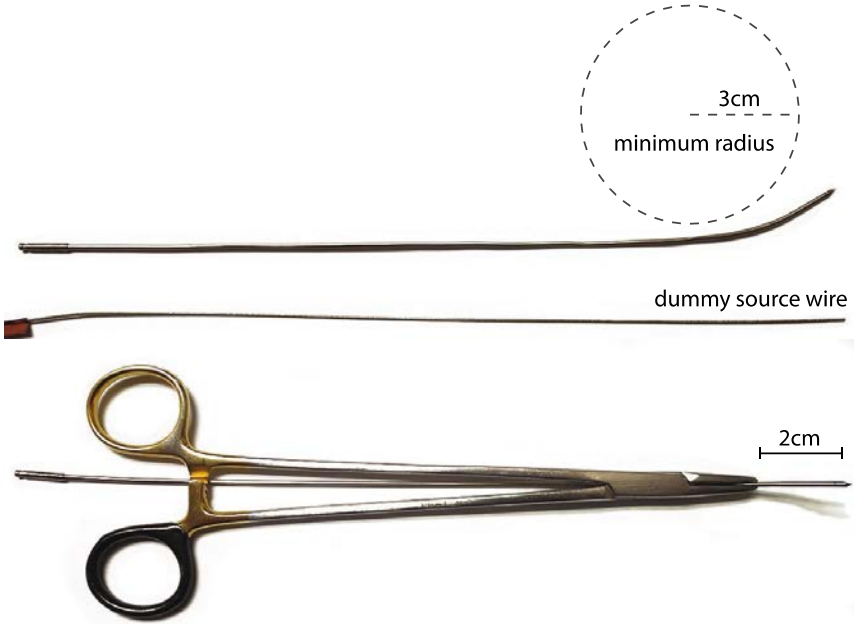
May–June, 2017 Volume 16, Issue 3, Supplement, Pages S114–S115

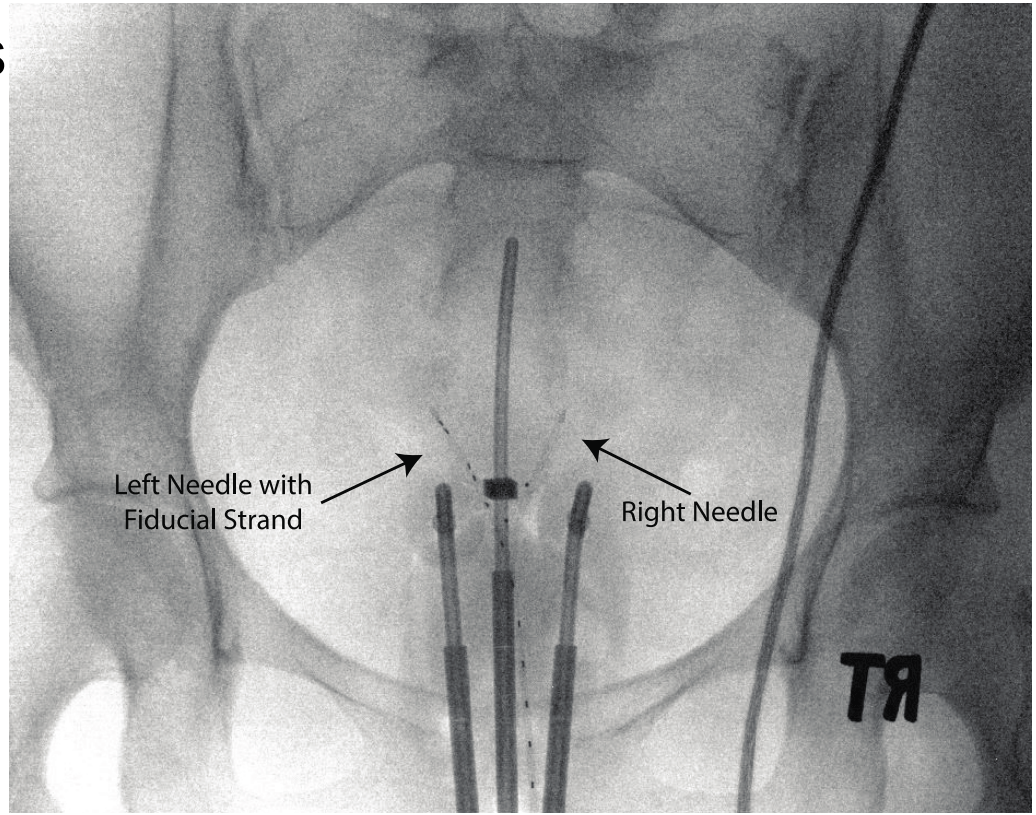


max. 3.3 mm). The catheter paths through the prostate region agreed to within 2mm, as shown in figure 1 (blue planned, red measured catheter paths), suggesting minimal lateral displacement of the catheter positions.

FILM: HDR GYN

Free-hand Interstitial Needles





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Olsen, Craciunescu, Chino, under review, IJ Contemporary Brachytherapy, 2017
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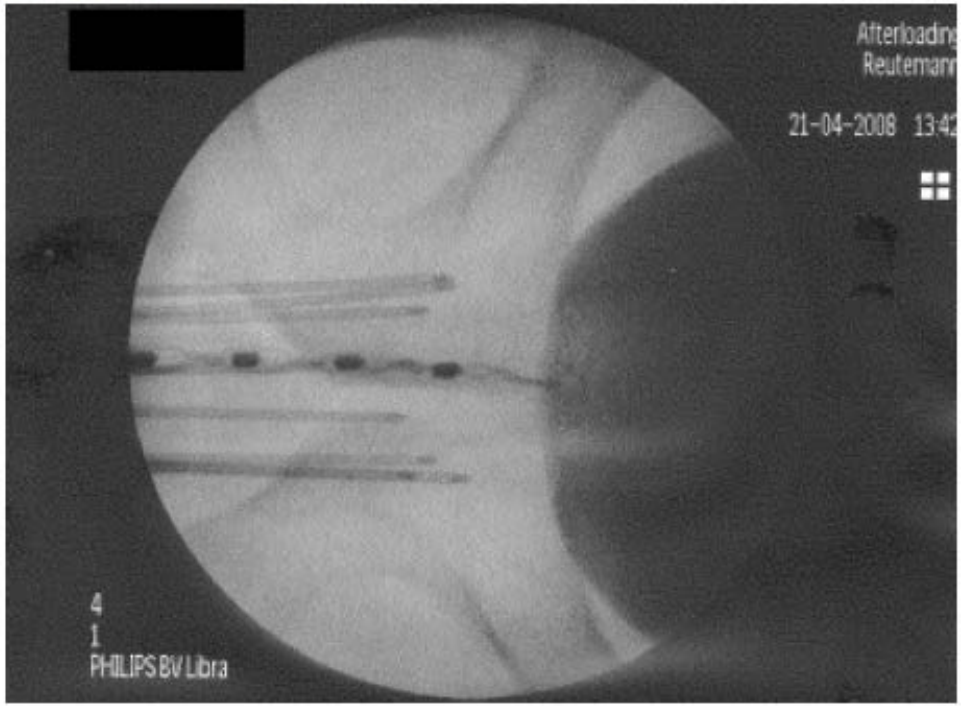
Fluoro: Prostate HDR needle checks

- Additional check by C-arm



- Campus Kiel, Clinic of Radiotherapy

Fluoro: HDR Applications

C-Arm imaging for brachytherapy source reconstruction: Geometrical accuracy

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(Received 31 December 2001; accepted for publication 25 February 2002; published 11 April 2002)

We study the accuracy of brachytherapy source reconstruction using C-Arm images. We use a phantom embedded with dummy ribbons in a regular pattern, placed at the rotation center of the C-Arm. With a commercial reconstruction jig, radiographic films are taken without the image intensifier. The average error in reconstructed seed coordinates is 0.1 cm. However, the jig is inconvenient for patient procedures. For C-Arm reconstruction without the jig, the magnifications of the image intensifier along orthogonal directions are different. We "stretch" the image to equalize the magnifications. Afterward, seed reconstruction has an average error of 0.1 cm in all directions. © *2002 American Association of Physicists in Medicine.* [DOI: 10.1118/1.1473136]

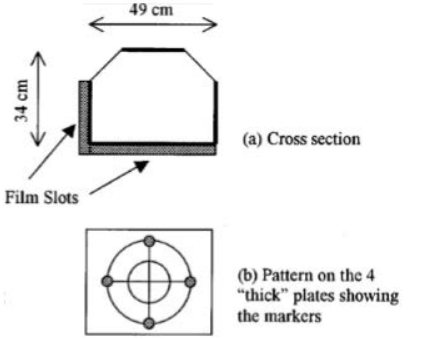

FIG. 2. Acrylic commercial reconstruction jig from Gammamed, with embedded radio-opaque markers on four "thick" plates.

This reconstruction method assumes there is a ribbon perpendicular to the C-Arm rotation plane. For HDR brachy-

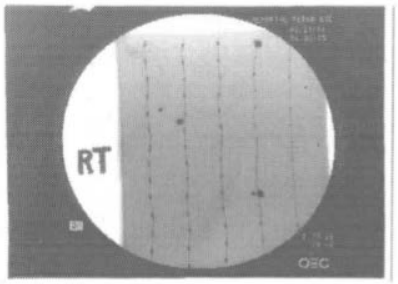

FIG. 4. AP image of the rectangular phantom taken with C-Arm fluoroscopy.

We first discuss the general difficulties in reconstruction using images straightforwardly without a jig. (a) The Image Intensifier (II) of the C-Arm is not designed for perfect images. The image plane of the II is not well defined, and geometric distortion is well known. (b) Sagging due to the heavy II produces uncertainties in distances and angles between the x-ray source, the phantom, and the II. (c) The C-Arm rotation is not isocentric, even by design. As shown in Fig. 3, the source–axis distance is angular dependent. (d) The ABACUS software assumes we have actual-size images taken at the "film" location. The II images, whether digital ones on a computer screen or hard copies from the fluoroscope printer, have different magnifications from those at the II plane.

The jig resolves all of the above-mentioned problems. Radiographic films are taken without the II, thus bypassing its accompanying issues: distortion, ill-defined plane, and sagging. The film records actual-size images at fixed distances. The markers are the solution for nonisocentricity. Coordi-

In conclusion, we have studied the use of a C-Arm and a commercial jig in brachytherapy localization. The jig reduces reconstruction errors, but poses risk of being too small and easily damaged, and inconvenient for clinical use. The II images without a jig, however, may provide accurate reconstruction, if the images are stretched along one direction to give the same magnification as the other orthogonal direction.

Fluoro: HDR GYN, C-arm, VIR-method

On the use of C-arm fluoroscopy for treatment planning in high dose rate brachytherapy

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(Received 13 March 2003; revised 4 June 2003; accepted for publication 19 June 2003; published 15 August 2003)

Treatment planning for brachytherapy requires the acquisition of geometrical information of the implant applicator and the patient anatomy. This is typically done using a simulator or a computed tomography scanner. In this study, we present a different method by which orthogonal images from a C-arm fluoroscopic machine is used for high dose rate brachytherapy treatment planning. A typical C-arm is not isocentric, and it does not have the mechanical accuracy of a simulator. One solution is to place a reconstruction box with fiducial markers around the patient. However, with the limited clearance of the C-arm this method is very cumbersome to use, and is not suitable for all patients and implant sites. A different approach is adopted in our study. First, the C-arm movements are limited to three directions only between the two orthogonal images: the C-orbital rotation, the vertical column, and the horizontal arm directions. The amounts of the two linear movements and the geometric parameters of the C-arm orbit are used to calculate the location of the crossing point of the two beams and thus the magnification factors of the two images. Second, the fluoroscopic images from the C-arm workstation are transferred in DICOM format to the planning computer through a local area network. Distortions in the fluoroscopic images, with its major component the "pincushion" effect, are numerically removed using a software program developed in house, which employs a seven-parameter polynomial filter. The overall reconstruction accuracy using this method is found to be 2 mm. This filmless process reduces the overall time needed for treatment planning, and greatly improves the workflow for high dose rate brachytherapy procedures. Since its commissioning nearly three years ago, this system has been used extensively at our institution for endobronchial, intracavitary, and interstitial brachytherapy planning with satisfactory results. [DOI: 10.1118/1.1598851]

Key words: high dose rate brachytherapy, treatment planning, C-arm, fluoroscopy, image distortion.

The virtual isocenter reconstruction (VIR) method.

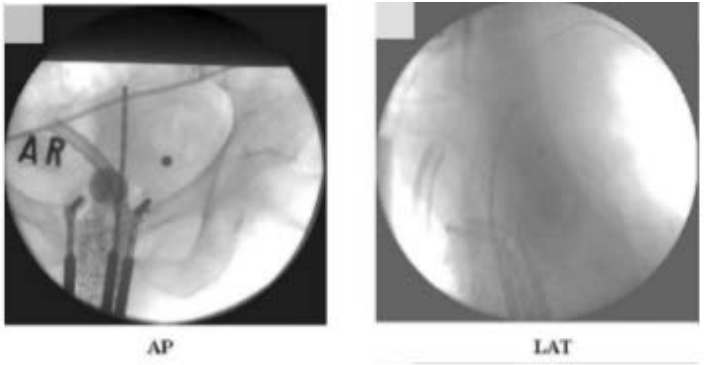

FIG. 7. Example of a Fletcher–Suite implant using the VIR method.

TABLE III. Summary of HDR implants performed from June 2000 to March 2003.

Implant type	No. of implants	Imaging device for planning
Endobronchial	45	C-arm
Esophageal	2	C-arm
GYN–Fletcher–Suite	6	C-arm
GYN–cylinder	79	(C-arm)
GYN–interstitial	1	CT
Sarcoma	12	Simulator
Head and Neck	6	C-arm, Simulator, CT
Breast–MammoSite	1	CT, (C-arm)
Total	152	

Fluoro: Real-time HDR TX Verification

Physics Contribution

Real-Time Verification of a High-Dose-Rate Iridium 192 Source Position Using a Modified C-Arm Fluoroscope

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Summary

High-dose-rate brachytherapy misdeliveries can occur at any institution. They can cause a disastrous accident but can be avoided with real-time verification. The simple application of conventional X-ray fluoroscopy for source position verification results only in halation because of the scattered photons from the source. We quadrupled the fluoroscopic dose per pulse to obtain better images and reduced the pulse rate by a factor of 4 to avoid overexposure. Using this method, we detected 2 errors among 2031 sessions.

Purpose: High-dose-rate (HDR) brachytherapy misdeliveries can occur at any institution, and they can cause disastrous results. Even a patient's death has been reported. Misdeliveries could be avoided with real-time verification methods. In 1996, we developed a modified C-arm fluoroscopic verification of an HDR Iridium 192 source position prevent these misdeliveries. This method provided excellent image quality sufficient to detect errors, and it has been in clinical use at our institutions for 20 years. The purpose of the current study is to introduce the mechanisms and validity of our straightforward C-arm fluoroscopic verification method.

Methods and Materials: Conventional X-ray fluoroscopic images are degraded by spurious signals and quantum noise from Iridium 192 photons, which make source verification impractical. To improve image quality, we quadrupled the C-arm fluoroscopic X-ray dose per pulse. The pulse rate was reduced by a factor of 4 to keep the average exposure compliant with Japanese medical regulations. The images were then displayed with quarter-frame rates.

Results: Sufficient quality was obtained to enable observation of the source position relative to both the applicators and the anatomy. With this method, 2 errors were detected among 2031 treatment sessions for 370 patients within a 6-year period.

Conclusions: With the use of a modified C-arm fluoroscopic verification method, treatment errors that were otherwise overlooked were detected in real time. This method should be given consideration for widespread use.

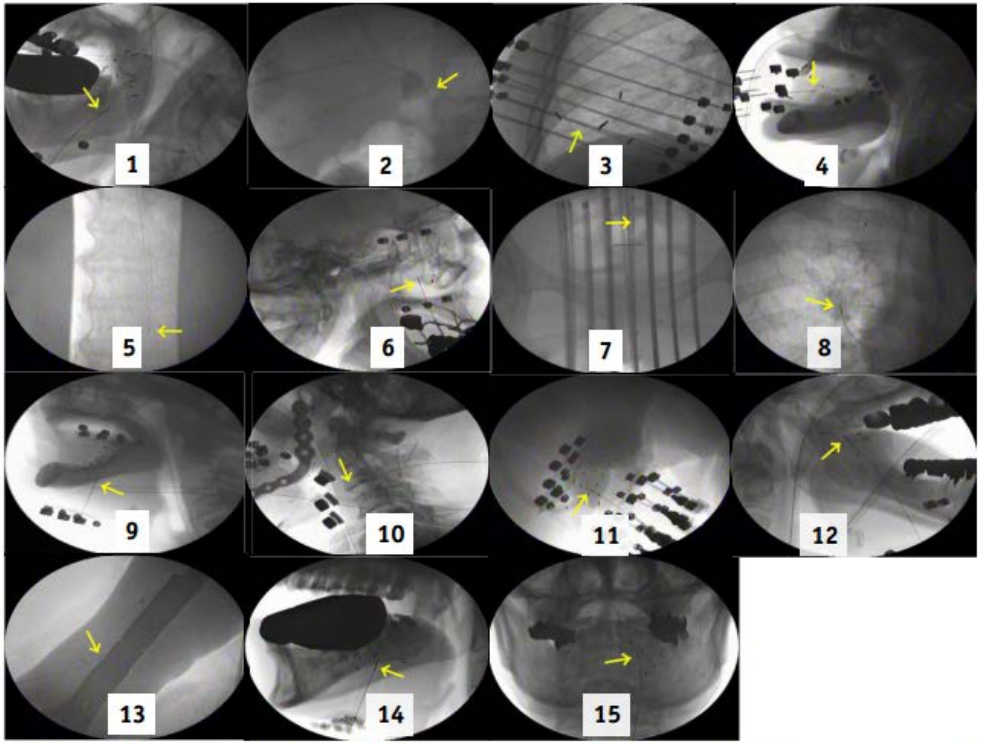


Fig. 2. Thumbnail images for high-dose-rate (HDR) Iridium 192 source videos. Interstitial brachytherapy for cancers of the head and neck (1, soft palate; 4, cheek; 6, facial skin; 9, tongue; 10, cervical lymph node; 12, anterior pillar; 14, mouth floor; 15, tonsil); cancers of the breast (3), cervix uteri (7), and penis (11); and soft tissue sarcoma of the thigh (13). Intracavitary brachytherapy for cancers of the bile duct (2), esophagus (5), and lung (8). The videos related to the figure 2 can be found at www.redjournal.org. Arrows indicate the respective HDR Iridium 192 source position. Small metals were implanted gold markers around the tumor volume (1, 3, 4, 6, 7, 9, 11, 12, 13, 14, 15).

kV-CBCT: With what?

- CBCT enabled simulators
- C-arms

- Note: reports of MV-CBCT use in brachytherapy:
  - Since MV CBCT images are less affected by high atomic number materials, such as metal objects, they can complement the information provided by kV CT(or CBCT) in images with metal-induced streak artifacts. Deschovich et al. , Brachytherapy,vol. 5, Issue 2, 85-86, 2006

kV-CBCT

- Commercially available systems:
  - Varian, Acuity

  - Nucletron, Simulinx

- C-arm CBCT

C-arm Cone-beam CT: General Principles and Technical Considerations for Use in Interventional Radiology

Robert C. Orth, MD, PhD, Michael J. Wallace, MD, and Michael D. Kuo, MD
for the Technology Assessment Committee of the Society of Interventional Radiology

Digital flat-panel detector cone-beam computed tomography (CBCT) has recently been adapted for use with C-arm systems. This configuration provides projection radiography, fluoroscopy, digital subtraction angiography, and volumetric computed tomography (CT) capabilities in a single patient setup, within the interventional suite. Such capabilities allow the interventionalist to perform intraprocedural volumetric imaging without the need for patient transportation. Proper use of this new technology requires an understanding of both its capabilities and limitations. This article provides an overview of C-arm CBCT with particular attention to trade-offs between C-arm CBCT systems and conventional multi-detector CT.

J Vasc Interv Radiol 2008; 19:814–821

Figure 1. Commercial C-arm-mounted flat-panel detector cone-beam CT system. (Avail-

CBCT: For what?

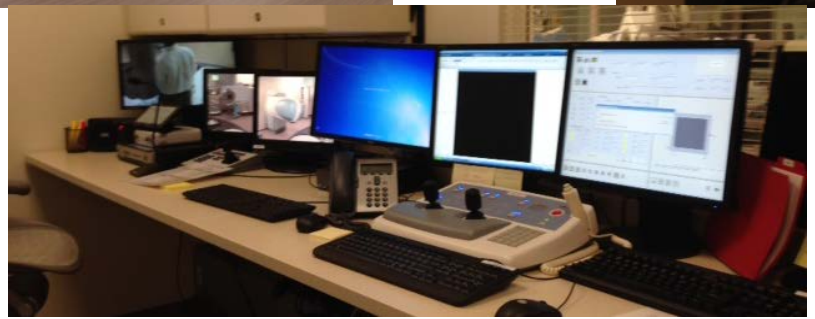
- GYN (G) & Prostate (P)
  - Planning (G, P): alone or with MRI/US
  - Applicator/Needle reconstruction and position (G, P)
  - Free-hand needle placement (G)
  - Gold marker displacement (P)
  - Post-plan/seed localization LDR (P)
  - C-arm CBCT for QA of LDR (P)
- Breast:
  - Multi catheter HDR interstitial
  - Balloon-based

CBCT

- Stand alone for planning
- As in-room imaging for applicator placement and pre-TX verification
- As part of a hybrid method when access to MRI is limited
  - Use of MRI at least at 1st FX and identify HRCTV/IRCTV
  - Continue subsequent fractions with CT or CBCT

Duke Brachy Suite

BrachySuite Console



CBCT Console

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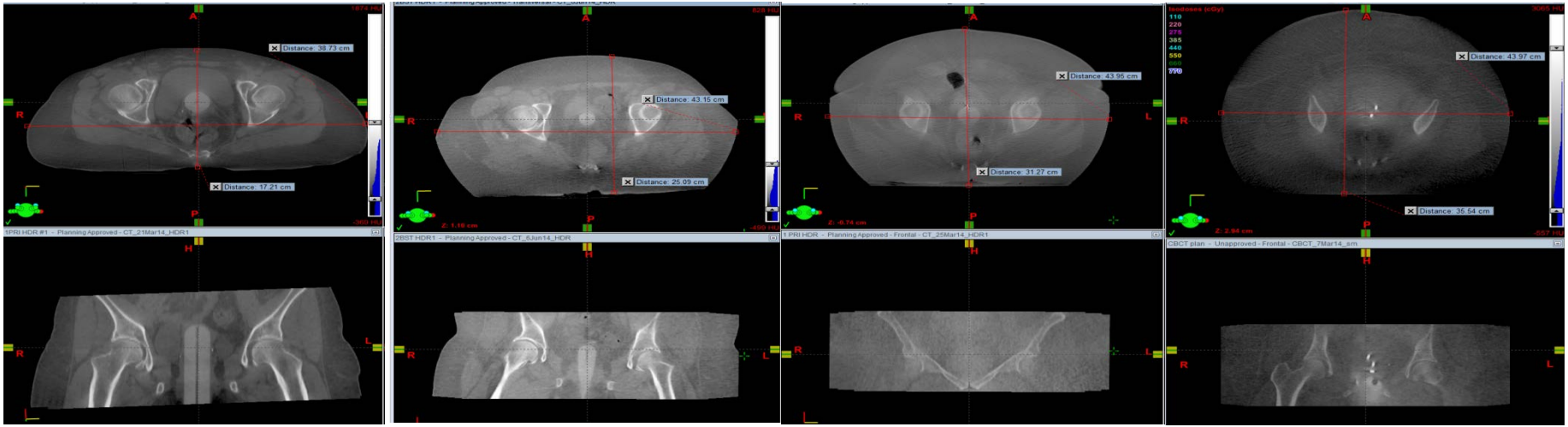
+ Access to 3.0 T MRI in Rad Onc on same hallway

Advantages of a CBCT in Brachy Suite

- Intra-operative imaging
- Large mechanical clearance (scan in stirrups, make adjustments)
- Can be easily combined with other imaging modalities
  - Primary, secondary (US, MRI)
- Minimize applicator/needles motion
  - Limiting the patient's motion is expected to limit post insertion applicator motion, which in return leads to more accurate planning.
- Good for applicator delineation
- Ability to image and verify before treatment
- Can scan, plan and treat under anesthesia

Image Quality vs. Patient Size

AP = 17 cm | AP = 25 cm | AP = 31 cm | AP = 35 cm



Technique: 150 SID, kVp = 120 , mA = 80, ms = 13

Large patients attenuate more, resulting in detection of fewer photons (increased noise, reduced signal, increased HU discrepancy, ie computer mistakes a thick absorber for high density material)

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CBCT vs CT (Female pelvis, small size)

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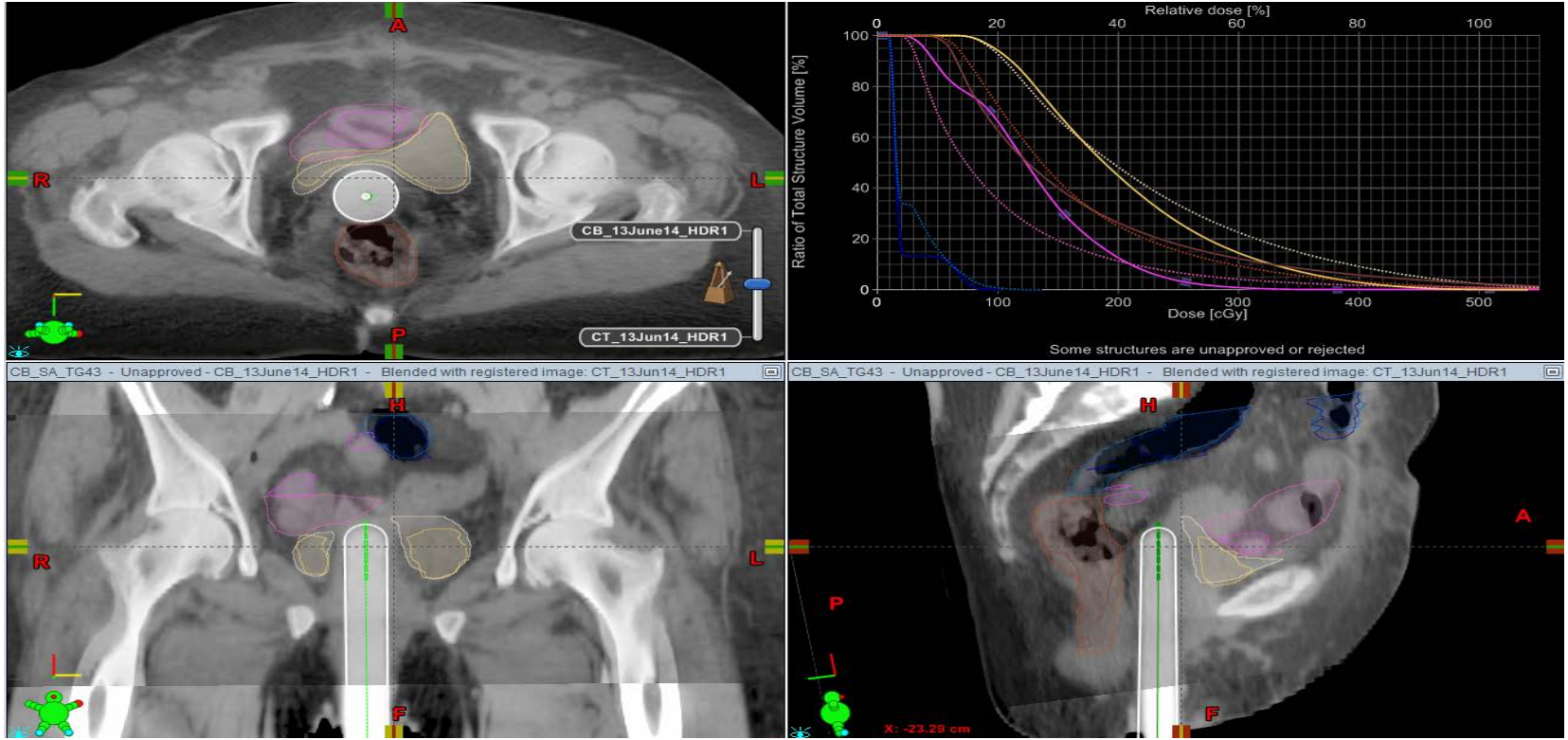
CT vs. CB contours



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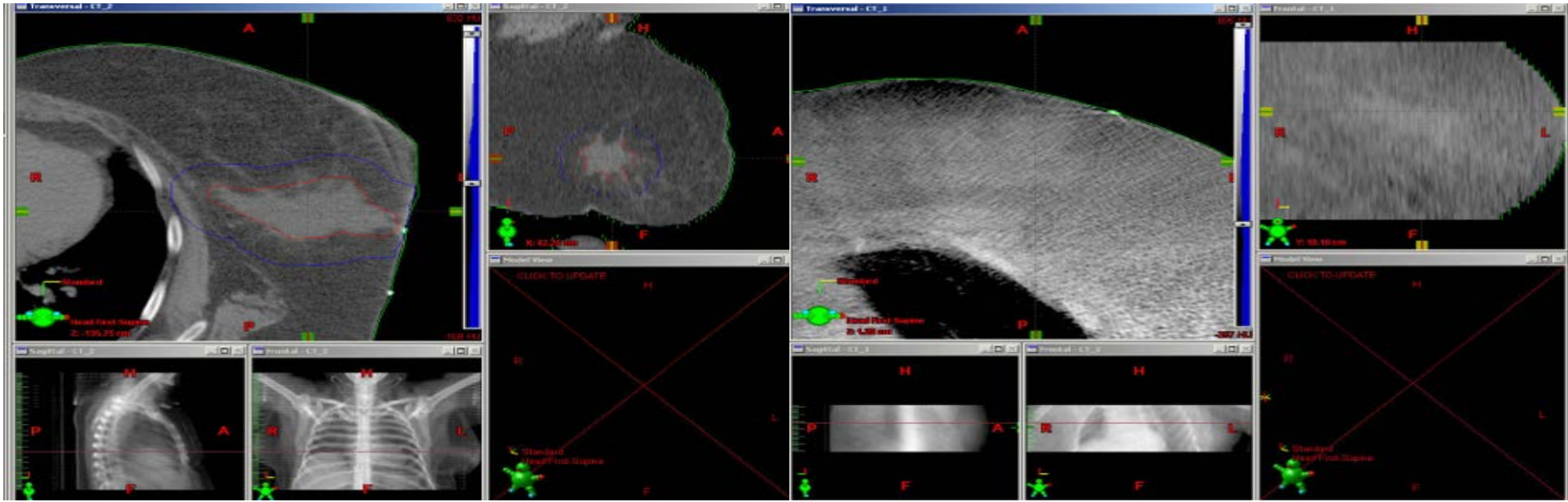
CBCT vs. CT (breast)



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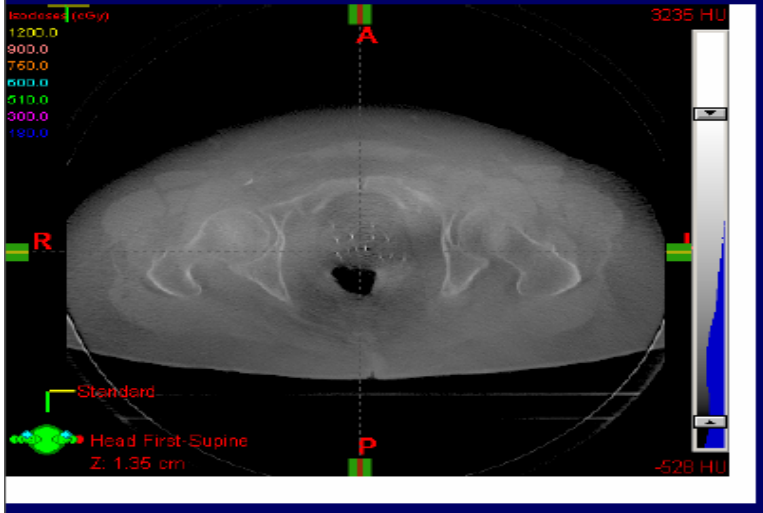
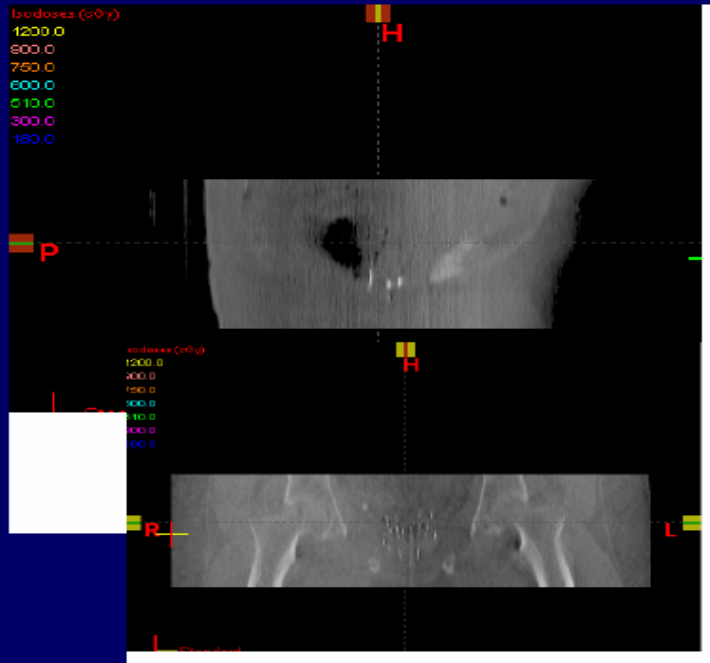
Courtesy of Dorin Todor, VCU

CBCT Prostate

Cone-Beam CT of the Prostate Seed Implant





Courtesy of B. Prestidge, Texas Cancer Clinic, San Antonio, 2004

GYN

GYN: CBCT-based planning → Opt imag protocol

Technical Note: Cone beam CT imaging for 3D image guided brachytherapy for gynecological HDR brachytherapy

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(Received 28 June 2010; revised 18 February 2011; accepted for publication 28 March 2011; published 9 May 2011)

Purpose: This paper focuses on a novel image guidance technique for gynecological brachytherapy treatment. The present standard technique is orthogonal x-ray imaging to reconstruct the 3D position of the applicator when the availability of CT or MR is limited. Our purpose is to introduce 3D planning in the brachytherapy suite using a cone beam CT (CBCT) scanner dedicated to brachytherapy. This would avoid moving the patient between imaging and treatment procedures which may cause applicator motion. This could be used to replace the x-ray images or to verify the treatment position immediately prior to dose delivery.
Methods: The sources of CBCT imaging artifacts in the case of brachytherapy were identified and removed where possible. The image quality was further improved by modifying the x-ray tube voltage, modifying the compensator bowtie filter and optimizing technical parameters such as the detector gain or tube current.
Results: The image quality was adequate to reconstruct the applicators in the treatment planning system. The position of points A and the localization of the organs at risk (OAR) ICRU points is easily achieved. This allows identification of cases where the rectum had moved with respect to the ICRU point which would require asymmetrical source loading. A better visualization is a first step toward a better sparing of the OAR.
Conclusions: Treatment planning for gynecological brachytherapy is aided by CBCT images. CBCT presents advantages over CT: acquisition in the treatment room and in the treatment position due to the larger clearance of the CBCT, thereby reducing problems associated to moving patients between rooms. © *2011 American Association of Physicists in Medicine*. [DOI: 10.1118/1.3578929]

Key words: image guided brachytherapy, cone beam CT, gynecological brachytherapy, HDR, planning, 3D imaging

V. CONCLUSIONS

By modifying a dedicated brachytherapy CBCT scanner and optimizing its imaging protocols adequate image quality was obtained for 3D brachytherapy treatment planning for GYN brachytherapy patients. This solution is an improvement over planning with orthogonal x-ray images, which is still common. It allows obtaining 3D images immediately prior to treatment giving the most pertinent information about organ positioning during the treatment. These images can be used as a verification tool but they can also be used for planning, enabling adaptive gynecological brachytherapy.

GYN Interstitial

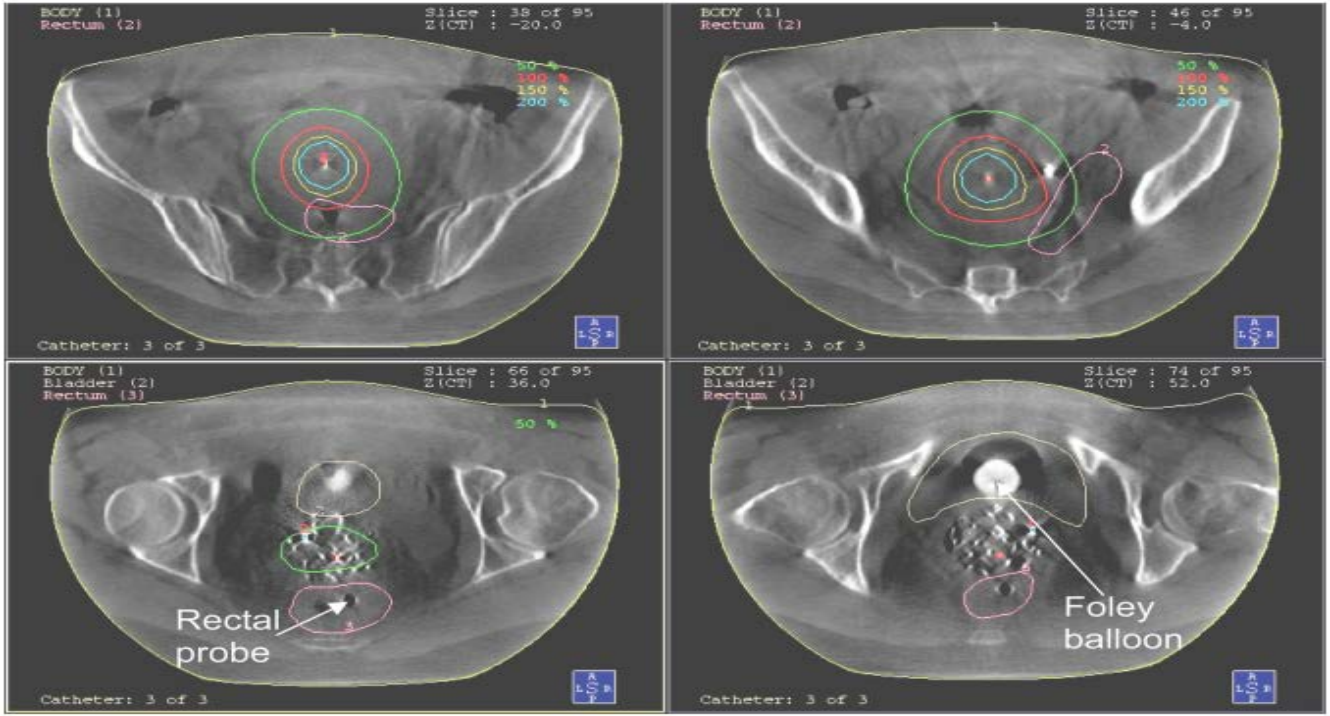

FIG. 5. Dose distribution and organs delineated in four slices of a CBCT scan of the same GYN patient. Pink contours delineate rectum and sigmoid. White contours represent bladder. All contours were drawn directly on the CBCT image.

Medical Physics, Vol. 38, No. 5, May 2011

GYN: CBCT-based planning

Int. J. Radiation Oncology Biol. Phys., Vol. 77, No. 4, pp. 1092–1097, 2010

0360-3016/$–see front matter

ELSEVIER

doi:10.1016/j.ijrobp.2009.06.036

CLINICAL INVESTIGATION **Cervix**

CONE BEAM CT-BASED THREE-DIMENSIONAL PLANNING IN HIGH-DOSE-RATE BRACHYTHERAPY FOR CERVICAL CANCER

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Purpose: To evaluate dose-volume histograms (DVHs) of bladder and rectum from the use of cone beam CT (CBCT)-based three-dimensional (3D) treatment planning in intracavitary high-dose-rate brachytherapy (HDRB) for cervical cancer patients and to compare these parameters with International Commission on Radiation Units and Measurements (ICRU) of rectal and bladder reference point dose measurements.
Methods and Materials: Thirteen patients with cervical cancer underwent HDRB insertions. CT-compatible tandem and ovoid applicators were used to obtain intraoperative CBCT images. The use of a rectal tube and injection of bladder contrast before scanning facilitated contouring the rectum and bladder. All patients underwent intraoperative orthogonal x-ray filming, and treatments were prescribed using standard two-dimensional planning and dosimetry. DVHs for the bladder and rectum were constructed for each treatment. The minimum dose in the most irradiated 2.0-cm^3 volume of bladder (B_{D2V}) and rectum (R_{D2V}) were determined from DVHs and compared to ICRU reference point estimates of bladder (B_{ICRU}) and rectum (R_{ICRU}) doses.
Results: Twenty-six CBCT-based plans were evaluated. The median B_{ICRU} dose (347 cGy; range, 164–601 cGy) was significantly lower ($p < 0.001$) than the median B_{D2V} (594 cGy; range, 260–969 cGy). The median R_{ICRU} dose (405 cGy; range, 189–700 cGy) was also significantly lower ($p = 0.037$) than the median R_{D2V} (488 cGy; range, 227–786 cGy).
Conclusions: CBCT-based 3D planning can be used in HDRB for cervical cancer and is a convenient alternative to CT-based planning, with the advantage of minimizing applicator motion. Correlation with late effects will further define the role of CBCT-based 3D dosimetry in HDRB planning. © 2010 Elsevier Inc.

Cone beam CT, Brachytherapy, Cervical cancer, ICRU, Three-dimensional planning.

GYN: CBCT-based Planning

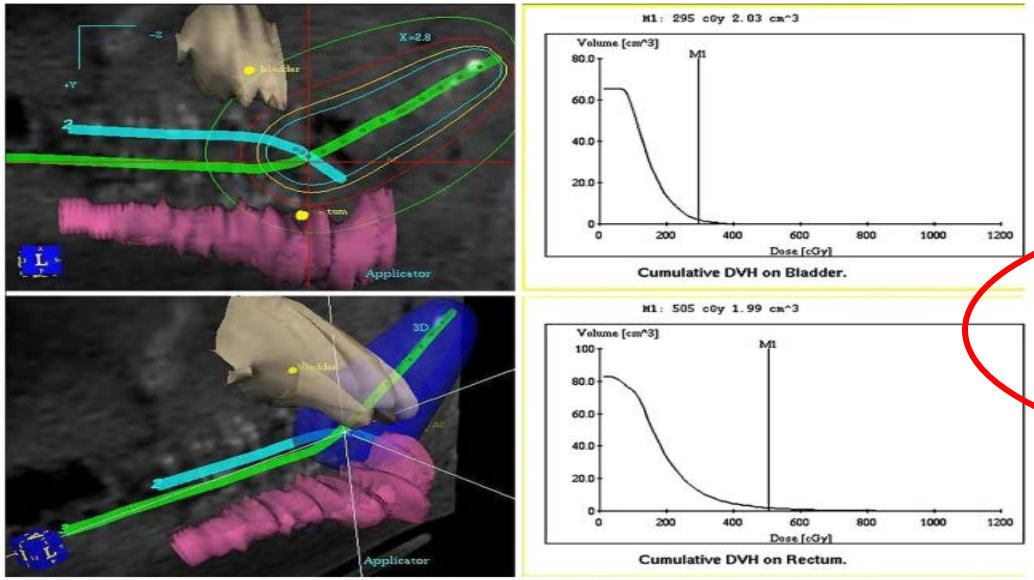

Fig. 2. 3D Reconstruction of the bladder and rectum during CBCT-guided ICBT planning. DVHs for the bladder and rectum are calculated using PLATO brachytherapy planning software. From the DVH, the minimum dose to the 2.0-cm^3 volume of bladder (BDV2) and rectal tissue (RDV2) receiving the highest dose was obtained

CONCLUSIONS

The Gynaecological GEC/ESTRO Working Group and the Image-Guided Brachytherapy Group have published recommendations for the parameters and methods to be followed in order to facilitate 3D-based planning in cervical cancer (3, 33, 34). This allows for consistency in reporting results from studies of image-guided brachytherapy. We have concluded that CBCT can be utilized for delineating the OARs and for assessing the dose to these organs by 3D volumetric planning in HDRB for cervical cancer. To follow the above-mentioned recommendations for image-guided brachytherapy, we intend to use CBCT images fused with MRI scans of the pelvis to delineate clinical target volumes, to prescribe dose to a volume, and to better assess the dose to normal structures. The calculated D2Vs to the rectum and bladder using CBCT planning are higher than the corresponding ICRU dose estimates. Correlation of these results with late treatment toxicity is needed to further evaluate the clinical relevance of CBCT-based volumetric dose calculations to the OARs.

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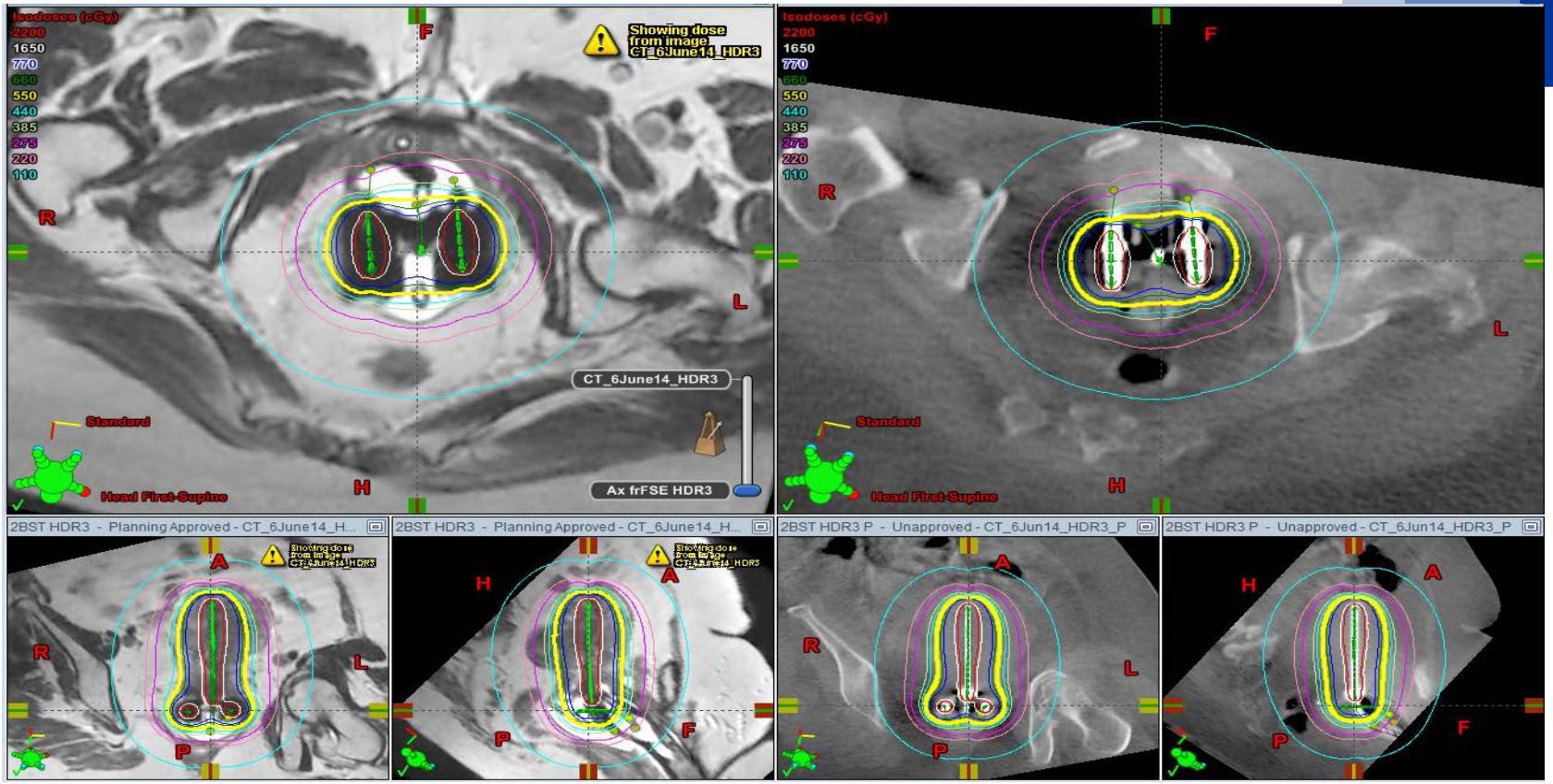

OAR: Good agreement with MRI (small patient size, good quality CBCT)

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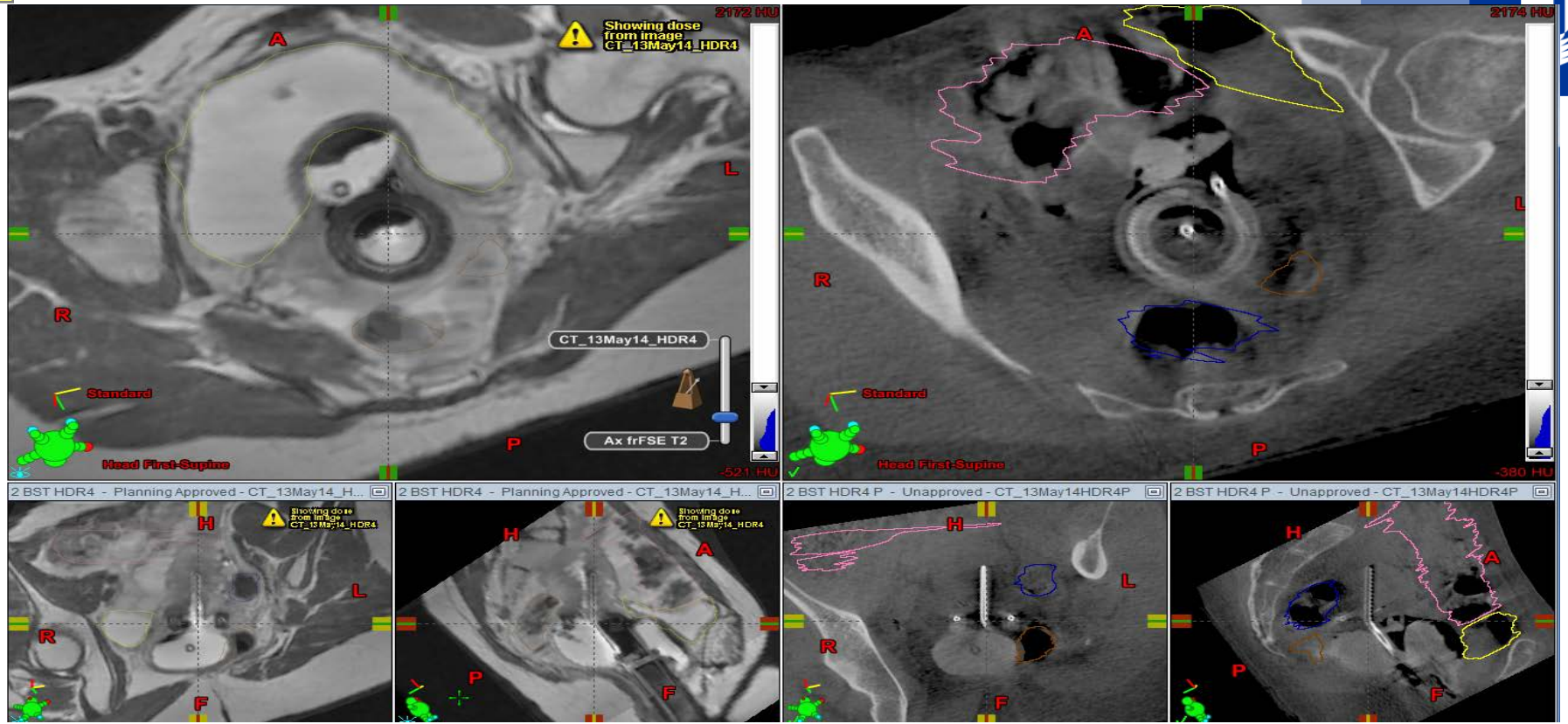

OAR: Poor agreement with MRI

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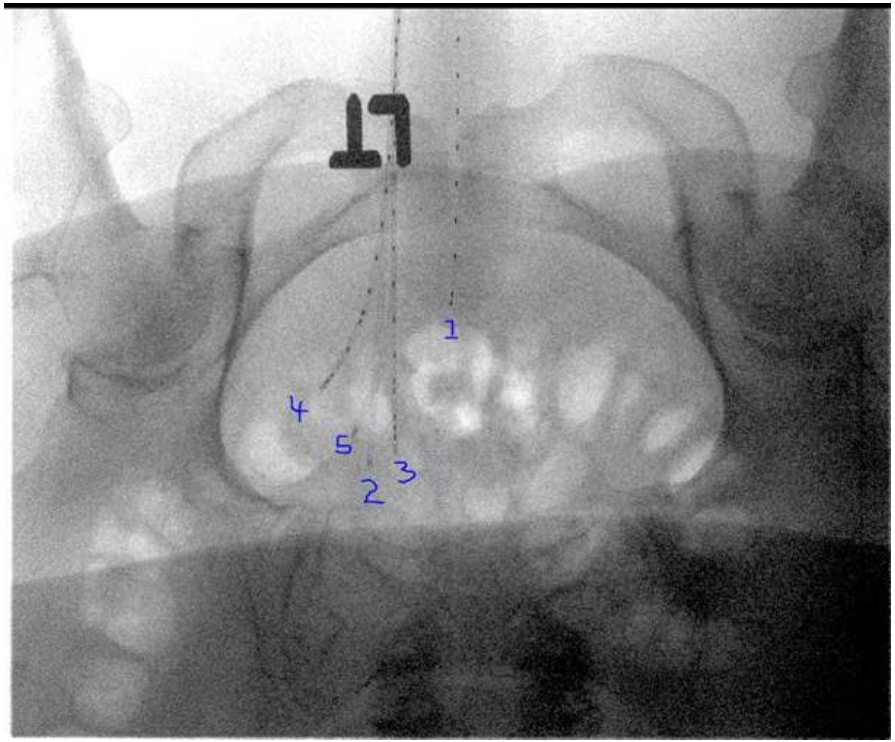
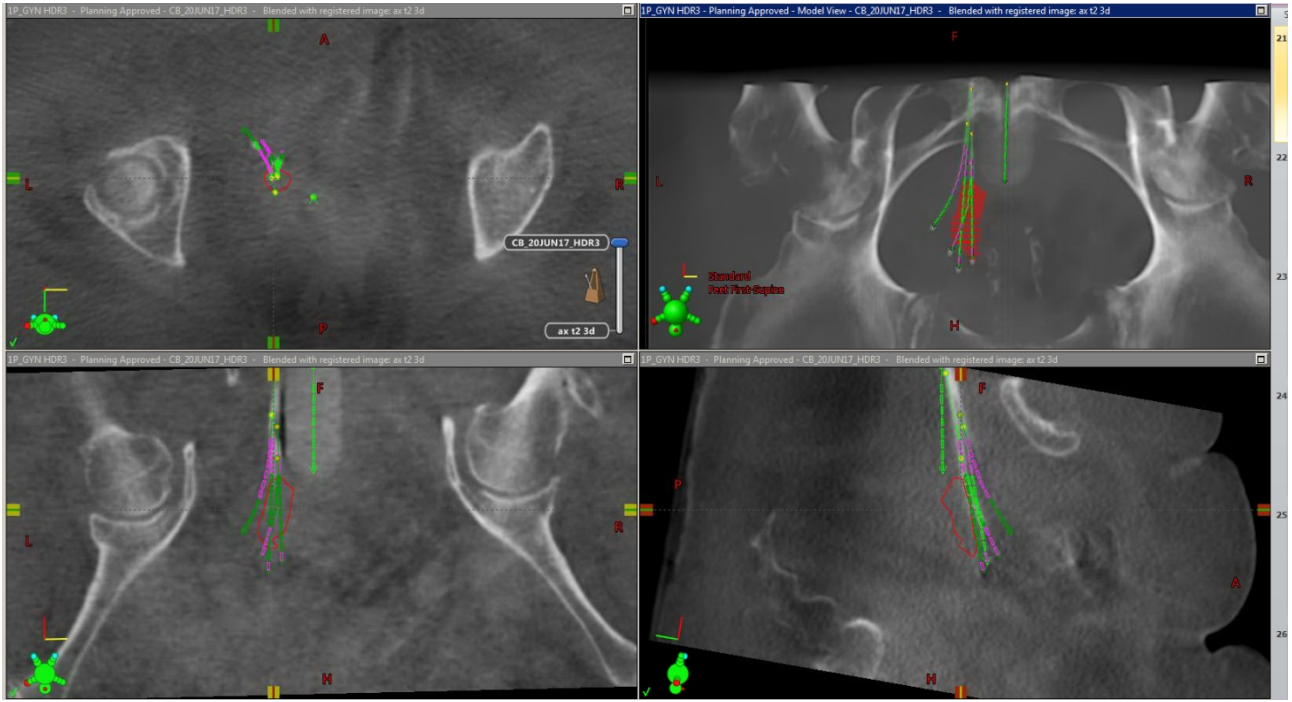
Craciunescu et. Al, Brachytherapy, vol. 15, S137-138, 2016

CBCT: GYN, Free-hand Needle Placement Guidance



CBCT: GYN, Free-hand Needle, Planning



CBCT: Needles reconstruction
MRI: HRCTV + normal tissue

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Prostate

High-dose-rate prostate brachytherapy based on registered transrectal ultrasound and in-room cone-beam CT images

Aniek J.G. Even[1,2,4], Tonnis T. Nuver[1,3,4,*], Hendrik Westendorp[1,3], Carel J. Hoekstra[3], Cornelis H. Slump[2], André W. Minken[1,3]

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ABSTRACT

PURPOSE: To present a high-dose-rate (HDR) brachytherapy procedure for prostate cancer using transrectal ultrasound (TRUS) to contour the regions of interest and registered in-room cone-beam CT (CBCT) images for needle reconstruction. To characterize the registration uncertainties between the two imaging modalities and explore the possibility of performing the procedure solely on TRUS.

METHODS AND MATERIALS: Patients were treated with a TRUS/CBCT-based HDR brachytherapy procedure. For 100 patients, dosimetric results were analyzed. For 40 patients, registration uncertainties were examined by determining differences in fiducial marker positions on TRUS and registered CBCT. The accuracy of needle reconstruction on TRUS was investigated by determining the position differences of needle tips on TRUS and CBCT. The dosimetric impact of reregistration and needle reconstruction on TRUS only was studied for 8 patients.

RESULTS: The average prostate V_{100} was 97.8%, urethra D_{10} was 116.3%, and rectum $D_{1\ cc}$ was 66.4% of the prescribed dose. For 85% of the patients, registration inaccuracies were within 3 mm. Large differences were found between needle tips on TRUS and CBCT, especially in cranial–caudal direction, with a maximum of 10.4 mm. Reregistration resulted in a maximum V_{100} reduction of 0.9%, whereas needle reconstruction on TRUS only gave a maximum reduction of 9.4%.

CONCLUSIONS: HDR prostate brachytherapy based on TRUS combined with CBCT is an accurate method. Registration uncertainties, and consequently dosimetric inaccuracies, are small compared with the uncertainties of performing the procedure solely based on static TRUS images. CBCT imaging is a requisite in our current procedure.

Keywords: Prostate; HDR brachytherapy; Transrectal ultrasound; Cone-beam CT; Registration

Conclusions

A successful HDR brachytherapy procedure is described in this article combining the advantages of the image properties of TRUS and CBCT. Contouring is performed on TRUS, and dose calculation is based on highly accurate needle reconstruction on CBCT. The registration uncertainties of this procedure are proven to be small and have minor impact on the prostate coverage and dose to the organs at risk. Major deviations were reported, especially in CC direction, for the reconstruction of the needles on TRUS images, resulting in substantial uncertainties in the dose distributions. Therefore, CBCT imaging is a requisite in our current procedure.

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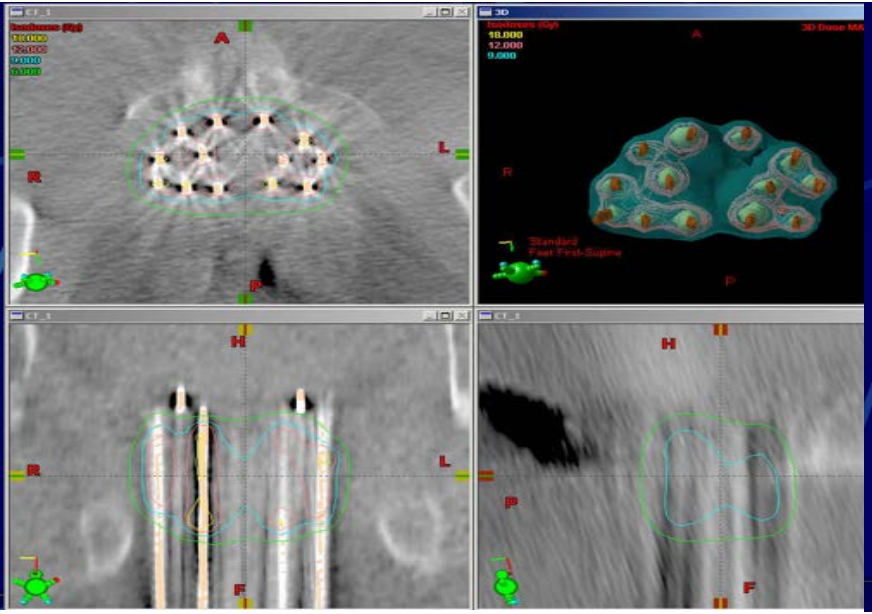
VCU setup, HDR Prostate



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Courtesy of Dorin Todor, VCU

C-arm CBCT for LDR prostate on-line verification

ELSEVIER

Brachytherapy 6 (2007) 231–237

BRACHYTHE

Intraoperative adaptive brachytherapy of iodine-125 prostate implants guided by C-arm cone-beam computed tomography–based dosimetry

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ABSTRACT

PURPOSE: (*1*) To demonstrate the feasibility of C-arm cone-beam computed tomography (CBCT)-based postplanning and subsequent adaptation of underdosed critical areas by adding remedial seeds during the transrectal ultrasound (TRUS)-guided implantation of ^{125}I seeds and (*2*) to assess the duration of this procedure.

METHODS AND MATERIALS: After finishing the implant, three fiducial markers were implanted and a TRUS study was performed to delineate the prostate. A C-arm CBCT unit with isocentric design was used to generate a CT data set to localize the seeds. The TRUS and CBCT data sets were coregistered by the radiation oncologist to assess the dosimetry of the implant. If underdosages existed at critical areas, dosimetry was adapted by adding remedial seeds while the patient was still under anesthesia.

RESULTS: Of 20 patients studied, 9 demonstrated underdosage in critical areas. On average four additional seeds were implanted, resulting in a mean D_{90} of 100.7% (increase 4.9%) and 117.5% (increase 17.8%) of the prescribed dose of 145 and 110 Gy, respectively. The average additional time involved in performing the adaptation procedure was less than 30 min.

CONCLUSIONS: C-arm CBCT-guided intraoperative postplanning during TRUS-guided brachytherapy for prostate cancer is both feasible and time efficient. The adaptation resulted in improved dosimetry of the prostate implants.

Keywords: Prostate; Intraoperative dosimetry; Adaptive brachytherapy; Transrectal ultrasound; Registration; Cone-beam CT

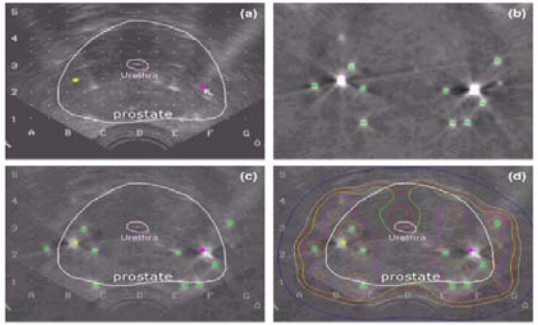

Fig. 1. (a) TRUS with contours and labeled fiducial markers; (b) CBCT with fiducial markers and labeled source positions; (c) registration of TRUS and CBCT on fiducial markers; (d) isodose lines and contours on registration of TRUS and CBCT.

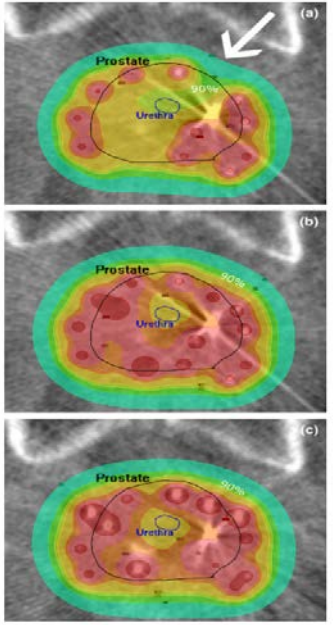

Fig. 2. Example of adaptation procedure, showing effect of correction of the implant. The 90% isodose is indicated in light green. (a) Dose deficiency marked by white arrow; (b) correction plan; and (c) final realized dose distribution with correction.

Post-Operative Seed Localization

Brachytherapy seed localization via iterative forward projection matching (IFPM) algorithm using intraoperative cone-beam-CT sinogram projections

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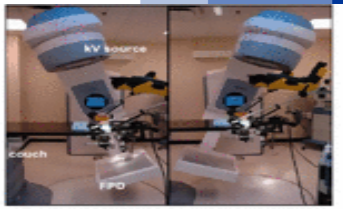

Fig. 1 Acuity imaging system for image-guided-brachytherapy procedure

Fast radioactive seed localization in intraoperative cone beam CT for low-dose-rate prostate brachytherapy

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Intra-Operative Seed Localization

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Proc. of SPIE Vol. 8671 867108-1

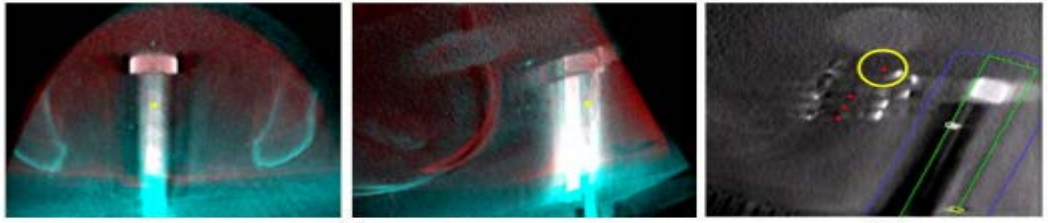

Figure 3. (a) Fused image of the template CBCT with TRUS probe (in cyan) and a patient's CBCT (in red) following automatic registration. Left: coronal view and Right: sagittal view. (b) Spatial information provided from the transferred planning seeds (red crosses) and the probe (in green) and its 1cm margin (in blue) work as an atlas to reduce the searching space for implant seeds (small white clusters). An example ROI from the upper right seed is show in yellow circle (sphere in 3D).

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Conclusions

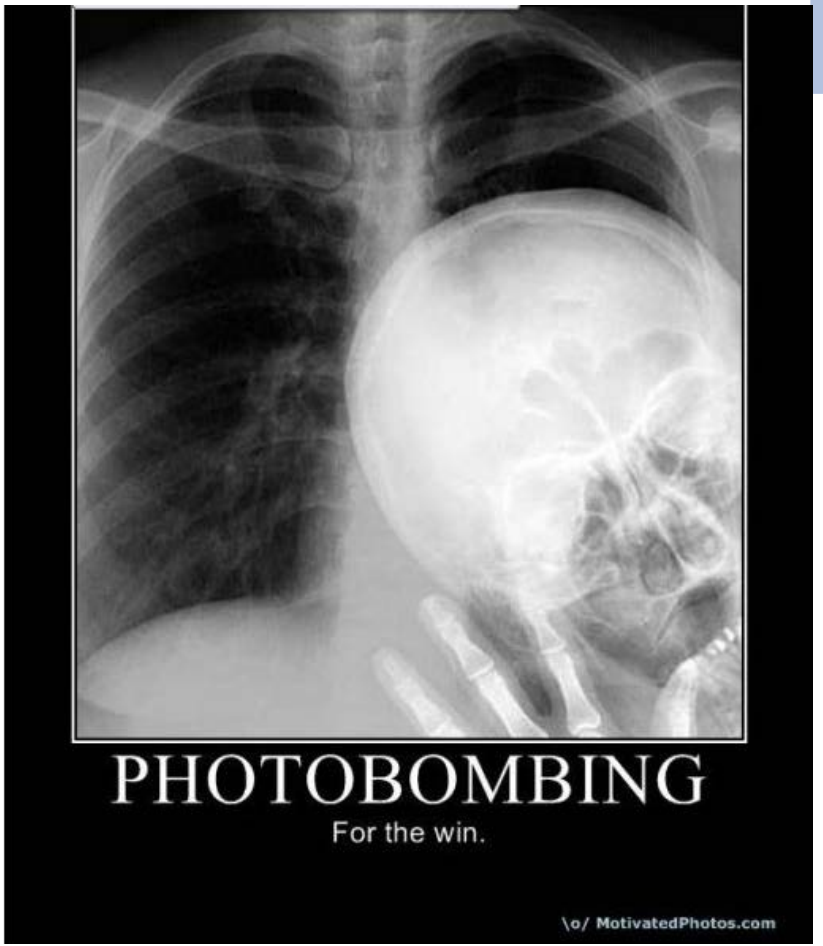
- X-ray films/Fluoro and kV-CBCT (Simulators, C-arms) have a role in “in-room” pre/post TX verification for several brachytherapy applications
- Thorough understanding of advantages and limitations is needed before using as sole imaging procedure for in-room treatment verification and/or planning

“Indeed, we often mark our progress in science by improvements in imaging.”

Martin Chalfie

Next → CT and MRI in room TX Verification

Thank you!



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