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An integrated system for clinical treatment verification of HDR prostate brachytherapy combining source tracking with pretreatment imaging

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ABSTRACT

PURPOSE: High-dose-rate (HDR) prostate brachytherapy treatment is usually delivered in one or a few large dose fractions. Poor execution of a planned treatment could have significant clinical impact, as high doses are delivered in seconds, and mistakes in an individual fraction cannot be easily rectified. Given that most potential errors in HDR brachytherapy ultimately lead to a geographical miss, a more direct approach to verification of correct treatment delivery is to directly monitor the position of the source throughout the treatment. In this work, we report on the clinical implementation of our treatment verification system that uniquely combines the 2D source-tracking capability with 2D pretreatment imaging, using a single flat panel detector (FPD).

METHODS AND MATERIALS: The clinical brachytherapy treatment couch was modified to allow integration of the FPD into the couch. This enabled the patient to be set up in the brachytherapy bunker in a position that closely matched that at treatment planning imaging. An anteroposterior image was acquired of the patient immediately before treatment delivery and was assessed by the Radiation Oncologist online, to reestablish the positions of the catheters relative to the prostate. Assessment of catheter positions was performed in the left-right and superior-inferior directions along the entire catheter length and throughout the treatment volume. Source tracking was then performed during treatment delivery, and the measured position of the source dwells were directly compared to the treatment plan for verification.

RESULTS: The treatment verification system was integrated into the clinical environment without significant change to workflow. Two patient cases are presented in this work to provide clinical examples of this system, which is now in routine use for all patient treatments in our clinic. The catheter positions were visualized relative to the prostate, immediately before treatment delivery. For one of the patient cases presented in this work, they agreed with the treatment plan on average by 1.5 mm and were identifiable as a predominantly inferior shift. The source tracking was performed during treatment delivery, and for the same case, the mean deviation from the planned dwell positions was 1.9 mm (max = 4.9 mm) for 280 positions across all catheters.

CONCLUSION: We have implemented our noninvasive treatment verification system based on an FPD in the clinical environment. The device is integrated into a patient treatment couch, and the process is now included in the routine clinical treatment procedure with minor impact on workflow. The system which combines both 2D pretreatment imaging and HDR 2D source tracking provides a range of information that can be used for comprehensive treatment verification. The system has the potential to meaningfully improve safety standards by allowing widespread adoption of routine treatment verification in HDR brachytherapy.

Keywords: Treatment verification; High-dose-rate brachytherapy; HDR; Source position; Flat panel detector

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Introduction

High-dose-rate (HDR) prostate brachytherapy treatment is usually delivered in one or a few large dose fractions. Poor execution of a planned treatment could have significant clinical impact, as high doses are delivered in seconds, and mistakes in an individual fraction cannot be easily rectified. The two primary causes of incorrect treatment delivery in HDR prostate brachytherapy are (*1*) human errors occurring at treatment delivery (1) and (*2*) unaccounted catheter displacement relative to the prostate (2). Both sources of treatment error are currently difficult to identify as few options are available to verify treatment delivery.

Verification of the treatment delivery parameters in HDR brachytherapy can be used as a method to identify possible human errors in the process but is often limited to (pretreatment) manual cross-checking of parameters, such as correct patient plan selection, indexer length, source activity, total treatment time, and correct transfer tube channel connection to the brachytherapy implant. Two recent review articles (3, 4) have emphasized the need for a comprehensive system to perform independent treatment verification, before and during treatment delivery, in HDR brachytherapy to ensure patient safety.

A ''first principles'' approach is to directly measure dose at a point in, or near, the treatment volume. However, *in vivo* dosimetry has many practical difficulties when applied to brachytherapy. Even in external beam radiotherapy, where treatment verification systems are more mature and widely used, surrogates are used, for example, dose to a transmission detector or electronic portal imaging device, from which correct delivery parameters are inferred (5). Point dosimetry is sometimes adopted as a further safety net—usually at a location outside the treatment volume, typically intracavitary or on the patient's skin.

Similar approaches to the adoption of *in vivo* dosimetry in HDR brachytherapy have highlighted these difficulties (6–11). First, dosimetry using very small detectors can be challenging due to the photon spectrum changing dramatically with distance from the source. Second, the interpretation of the measured dose can be difficult mainly due to the inherent uncertainty in the position of the detector relative to the brachytherapy source. The position of both, relative to the anatomy, can be extremely difficult to ascertain.

Given that most potential errors in HDR brachytherapy ultimately lead to a geographical miss for all or part of the treatment dose, a more direct approach to verification of correct treatment delivery is to directly monitor the position of the source throughout the treatment.

We have previously shown that source tracking can be achieved using a 2D array detector such as an electronic portal imaging device (12) or flat panel imaging detector. By using a high-resolution imaging array, this function can be combined with pretreatment imaging of the implant and sufficient anatomical reference information to verify position of the brachytherapy source (13) relative to the target volume. A further advantage of the pretreatment imaging is to ensure that any small changes in the implant geometry are accounted for during source-tracking verification. Other approaches for treatment verification are being developed with electromagnetic tracking showing potential for pretreatment and source-tracking verification (14). Geometric verification of the implant before treatment is also the goal of that system.

The imaging data used for treatment planning of HDR prostate brachytherapy (e.g., CT, MR, or US) represents a ''snap shot'' in time of the implant geometry, but changes do occur over the time taken from planning to treatment delivery. Swelling and other influences impact the position of the interstitial catheters relative to the prostate anatomy, and so pretreatment implant verification using imaging is recommended (15, 16). Interfraction and intrafraction catheter displacements have been reported (17–20) and occur largely in the cranial-caudal direction particularly for CT- and MR-based planning, where imaging to treatment times are longer than for interoperative trans-rectal ultrasound -planned approaches. This unaccounted-for catheter displacement represents a geographical miss treatment delivery error and could have a significant impact on dosimetry.

Our approach to treatment verification is a two-step approach; (*1*) perform pretreatment imaging to reevaluate the position of the catheters immediately before treatment delivery and (*2*) track the position of the source as it delivers the treatment verifying it is executed as planned. Discrepancies observed between measured and planned source positions can be evaluated and used to identify possible human errors or other hardware or software system failures. We have previously established the capabilities of the system and demonstrated examples of information provided by the system to aid in identification of errors (13).

In this work, we report on the clinical implementation of our treatment verification system that uniquely combines the source-tracking capability with pretreatment imaging, using a single flat panel detector (FPD). The FPD is used to perform pretreatment implant imaging immediately before treatment, identifying possible catheter displacement. Any observed catheter displacement can then be accounted for in the source tracking verification procedure. This novel, noninvasive approach, using an FPD embedded in the treatment couch, provides comprehensive information for independent treatment verification in HDR prostate brachytherapy. Here, we describe the implementation, its integration into the clinical workflow, and present clinical examples of treatment verification capabilities.

Method

Treatment protocol

The Alfred Health Radiation Oncology department currently performs HDR prostate brachytherapy boost along with an external beam component. Our technique is similar to that of many modern HDR prostate