ELSEVIER

Brachytherapy ■ (2017) ■

BRACHYTHERAPY

Assessment of the implant geometry in fractionated interstitial HDR breast brachytherapy using an electromagnetic tracking system

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ABSTRACT

PURPOSE: During the partial-breast treatment course by interstitial brachytherapy, electromagnetic tracking (EMT) was applied to measure the implant geometry. Implant-geometry variation, choice of reference data, and three registration methods were assessed.

METHODS AND MATERIALS: The implant geometry was measured in 28 patients after catheter implantation (EMT_{bed}), during CT imaging (EMT_{CT}), and in each of up to $n = 9$ treatment fractions ($EMT_{F(k),\ k\ =\ 1,\ 2,\ldots\ n}$). $EMT_{F(k)}$ were registered to the planned implant reconstruction (CT_{plan}) by using all dwell positions (DPs), the button centers, or three fiducial sensors on the patient's skin. Variation in implant geometry obtained from $EMT_{F(k)}$ was assessed for EMT_{bed}, EMT_{CT}, and CT_{plan}.

RESULTS: EMT was used to measure 3932 catheters. A duration of 6.5 ± 1.7 min was needed for each implant measurement (mean, 17 catheters) plus setup of the EMT system. Data registration based on the DP deviated significantly lower than registration on button centers or fiducial sensors. Within a registration group, there was a <0.5-mm difference in the choice of reference data. Using CT_{plan} as reference for registration, the mean residual distance of DPs on EMT-derived DPs was found at 2.1 ± 1.6 mm (EMT_{bed}), 1.3 ± 0.9 mm (EMT_{CT}), and 2.5 ± 1.5 mm ($EMT_{F(k)}$).

CONCLUSIONS: EMT can assess the implant geometry in high-dose-rate interstitial brachytherapy breast treatments. EMT_{bed}, EMT_{CT}, and CT_{plan} data can serve as reference for assessment of implant changes.

Keywords: Brachytherapy; Electromagnetic tracking; Interfractional changes; Quality assurance

Introduction

High-dose-rate interstitial brachytherapy (HDR-iBT) is a proven treatment option for breast cancer in a combined approach with surgery and/or external beam radiation therapy (1−4). After implantation of multiple catheters into the breast, CT imaging is the basis for treatment planning, that is, implant reconstruction, structure definition, dwell-position (DP) optimization, and dose calculation. Treatment is typically delivered in several fractions with appropriate quality control (QC) measurements before delivery of the first treatment fraction. As reported by several authors, a number of uncertainties and errors might influence the success of treatment delivery. Among them are uncertainties related to organ motion/deformation or implant movements (5, 6) and errors such as wrong transfer tube length or swapped/mislabeled catheters (7, 8).

Unlike other stereotactic treatment methods for breast cancer (e.g., intensity modulated radiation therapy [IMRT]), image-based verification of the patient's anatomy and the implant online or before each fraction is not a standard practice for HDR-iBT. Individual studies show the feasibility of daily CT imaging in MammoSite-based breast treatments (9, 10) or treatments in other organs (11−13). In addition, *in vivo* dosimetry (IVD) is promising to ensure the validity of treatment-planning assumptions (8) but not yet performed on a widespread level.

A potential new modality for improved daily QC measurements of the catheter geometry is electromagnetic tracking (EMT). EMT is already used for accurate, dose-free, and efficient spatio-temporal localization of sensors in multiple fields of medicine (14). Active research toward applications in brachytherapy started recently (15). So far, brachytherapy-related research focuses on feasibility

Received 30 January 2017; received in revised form 17 September 2017; accepted 13 October 2017.

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1538-4721/$ - see front matter
https://doi.org/10.1016/j.brachy.2017.10.007

studies in phantoms concerning precision and accuracy. The results demonstrate the feasibility of EMT-based implant definition (16–20) and error detection (21) in a phantom and thus stimulate further investigation in clinical studies. Recently, Beaulieu *et al.* reported on an EMT treatment platform for prostate cancer treatments (22).

The purpose of this article was to provide a description of, to our knowledge, the first clinical introduction of EMT for daily implant-geometry measurements in HDR-iBT treatments of the female breast. The focus is on a quantitative assessment of the variability of the implant geometry over the course of the fractionated treatment. In addition, different registration options are studied in combination with different reference data sets.

Methods and materials

Patient cohort and treatment scheme

We report on 28 breast cancer cases who were treated by HDR-iBT in the period of January 2015 to May 2016 according to our clinical workflow. Without changes in the treatment process, it was possible to introduce EMT. In the following, this protocol is briefly summarized. Patients are implanted in general anesthesia with typically 10–26 catheters (6F Flexible Implant Tubes; Elekta, Veenendaal, The Netherlands) for covering the tumor volume in a (female) breast. After a period of ~1 h to recover from anesthesia, patients are transferred to the CT scanner (Sensation Open, Siemens Healthcare AG, Erlangen, Germany) in the same clinic. Images of the implanted breast are acquired (slice thickness: 2.0 mm, 512 × 512 matrix covering the ipsilateral breast) in free breathing for the patients from P01 to P24 and in command-based end expiration from P25 to P28. Treatment planning (Oncentra Brachy v4.3, Elekta, Veenendaal, The Netherlands) starts by manual definition of the implant geometry via stepwise linear reconstruction of the air-filled catheters and the definition of the planning target volume (PTV) and other volumes of interest (23). DPs are defined for each catheter starting at 5 mm from the center of the distal button (tip end) and following the reconstructed catheter points in 2.5-mm intervals. Analogous to the used DPs from the CT_{plan} (see Fig. 1), the corresponding DPs were generated along the tracked catheters points (see subsection "Data acquisition").

The goal of the optimization in the treatment planning is a PTV coverage of $V_{100} > 90\%$ at a dose nonuniformity ratio = V (1.5•D_{ref})/V (D_{ref}) < 0.30 with a limitation of the dose to the skin surface to <70% of the prescribed dose D_{ref} (24). After patient-specific QC measurements, treatments are delivered with an Ir-192–loaded afterloader (model: microSelectron-HDR v3; Elekta, Veenendaal, The Netherlands) typically administered by dosimetrists (medical technology assistants). Depending on the fractionation scheme, either 2 × 6 Gy for boost patients or 9 × 3.8 Gy for interstitial brachytherapy (iBT) alone, the treatment ends the following day or the fifth treatment day, respectively.

Within the framework of this standard clinical protocol, we used EMT to determine the geometry of the implant by reconstructing DPs at the various stages of the treatment workflow (EMT-determined DPs [DP_{EMT}]). The study was approved by the institutional review board of the Friedrich-Alexander-Universität Erlangen-Nürnberg (#355_14 B, 2014). All patients signed an informed consent. The EMT data had no influence on the treatment, that is, they were acquired for study purposes only with the aim to evaluate the clinical feasibility of EMT in iBT breast patient treatments and for assessment of potential changes in the implant geometry over the treatment course. Details of the EMT measurement are described in section "Data acquisition".

The study was initiated in January 2015 after a period of quality assurance of the EMT system and phantom testing (19). Patients were recruited consecutively afterward.

Data acquisition

The DP_{EMT} were determined using the Aurora V3 system (Northern Digital Instruments, Waterloo, Canada) at various stages of the treatment workflow as indicated in Fig. 1. During the monitoring period after implantation,

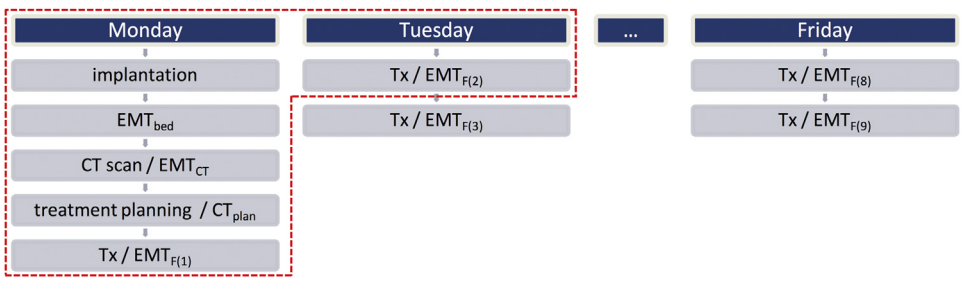

Fig. 1. Workflow of the treatment and the accompanying EMT measurements which are performed just after surgical implantation of the catheters in a patient bed (EMT_{bed}), immediately after CT acquisition (EMT_{CT}) and after delivering the irradiation (Tx) during each treatment fraction ($EMT_{F(k),\ k\ =\ 1,\ 2,\ldots\ n}$). iBT as a boost to conventional external beam radiation therapy follows in our clinic the same planning and treatment procedures but ends after k = 2 as indicated by the dashed frame. EMT = electromagnetic tracking; iBT = interstitial brachytherapy.