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PHYSICS CONTRIBUTION

EVALUATION OF ARTIFACTS AND DISTORTIONS OF TITANIUM APPLICATORS ON 3.0-TESLA MRI: FEASIBILITY OF TITANIUM APPLICATORS IN MRI-GUIDED BRACHYTHERAPY FOR GYNECOLOGICAL CANCER

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Purpose: The aim of this study was to characterize the levels of artifacts and distortions of titanium applicators on 3.0-Tesla magnetic resonance imaging (MRI).

Methods and Materials: Fletcher-Suit-Delclos-style tandem and ovoids (T&O) and tandem and ring applicator (T&R) were examined. The quality assurance (QA) phantoms for each applicator were designed and filled with copper sulphate solution (1.5 g/l). The artifacts were quantified with the registration of corresponding computed tomography (CT) images. A favorable MR sequence was searched in terms of artifacts. Using the sequence, the artifacts were determined. The geometric distortions induced by the applicators were quantified through each registration of CT and MRI without applicators. The artifacts of T&O were also evaluated on *in vivo* MRI datasets of 5 patients.

Results: T1-weighted MRI with 1-mm slice thickness was found as a favorable MR sequence. Applying the sequence, the artifacts at the tandem tip of T&O and T&R were determined as 1.5 ± 0.5 mm in a superior direction in phantom studies. In the ovoids of T&O, we found artifacts less than 1.5 ± 0.5 mm. The artifacts of a T&O tandem *in vivo* were found as less than 2.6 ± 1.3 mm on T1-weighted MRI, whereas less than 6.9 ± 3.4 mm on T2-weighted MRI. No more than 1.2 ± 0.6 mm (3.0 ± 1.5 mm) of distortions, due to a titanium applicator, were measured on T1-weighted MRI (T2-).

Conclusion: In 3.0-Tesla MRI, we found the artifact widths at the tip of tandem were less than 1.5 ± 0.5 mm for both T&O and T&R when using T1-weighted MRI in phantom studies. However, exclusive 3.0-Tesla MRI-guided brachytherapy planning with a titanium applicator should be cautiously implemented.

Artifacts, distortions, brachytherapy, 3D image-guided brachytherapy, MRI-guided brachytherapy.

INTRODUCTION

Use of magnetic resonance imaging (MRI) in brachytherapy (BT) for cervical cancer is currently gaining momentum (1–3). It allows clinicians to deliver adaptive BT radiation based on macroscopic tumor volume and tumor regression which has been limited in utilizing computed tomography (CT). Pioneering investigations are currently demonstrating that MRI-guided BT achieves local tumor control of ≥85% in locally advanced cervical cancer with low treatment-related gastrointestinal and urinary late morbidity (Grade 3 or Grade 4) (4). A low–magnetic-field MR system of 1.5 or 2.0 Tesla has been used. However, current 1.5-Tesla MRI is limited by its signal-to-noise ratio (SNR) (5), particularly its ability to accurately analyze the uterine cervix and the macroscopic tumor regions (5, 6) mainly resulting from its low SNR. Considerable intrascan motion artifacts exist because of its extended acquisition time (see comparison in Ref. 5, Fig. 3).

Recently, MR scanners with magnetic field strengths of 3.0 Tesla have become available for clinical use. The 3.0-Tesla MR system has approximately double the SNR of a 1.5-Tesla system. Therefore, the image contrast in the uterine cervix and vagina is significantly higher (5) and the image acquisition speed is substantially faster (7). For MRI-guided BT, a plastic applicator has been suggested as the most suitable applicator. No accident reports have been introduced in the literature regarding its mechanical

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Conflict of interest: none.

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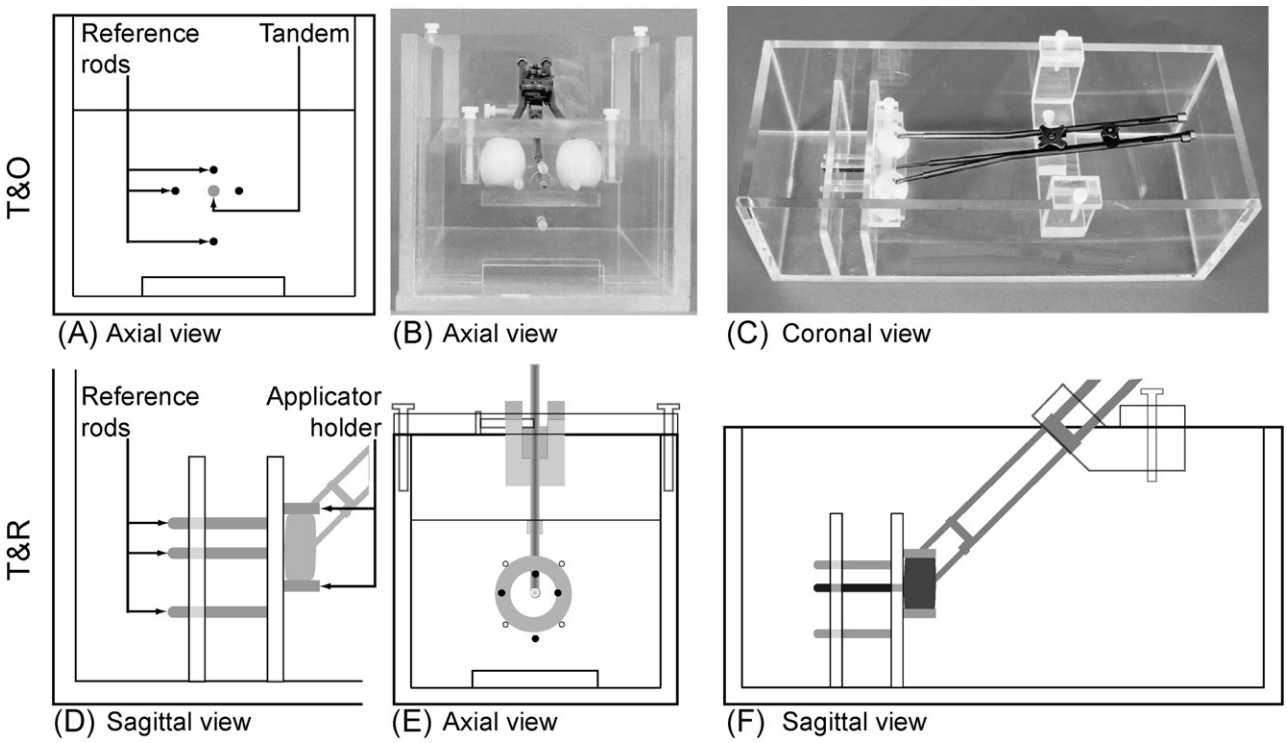

Fig. 1. Quality assurance (QA) phantoms, dedicated for tandem and ovoid applicator (T&O) in panels A to C and tandem and ring applicator (T&R) in panels D to F, were developed for validating artifacts and distortions, and furthermore for QA of 3D image guided brachytherapy treatment planning procedures.

strength. Nonetheless, clinical experience with plastic applicators has been relatively limited and the plastics used in gynecological applicators should be thoroughly verified through the trials on extended patients. The potential risk because of its inferior strength has remained a clinical concern, along with its maximum dimension of ≥5.5 mm. By contrast, a titanium applicator is more robust and measures smaller with minimum dimensions of 3.2 mm in diameter in the intrauterine section. However, the investigation of titanium applicator use in MRI-guided BT is limited to only the study of Haack *et al.* (1). Haack *et al.* studied each plastic and titanium tandem and ring applicator (T&R) and titanium needles using a 1.5-Tesla MR system. To the best of our knowledge, this study is the first to investigate both titanium T&R and tandem and ovoids applicator (T&O; or tandem and colpostats) in MRI-guided BT. In addition, it is the first study on the use of titanium applicators with a 3.0-Tesla MR system. Our first task was to verify the safety concerns (8) (especially radiofrequency [RF] heat) that are elaborated on in the Discussion section.

In this study, we determined an artifact-favorable MR sequence to obtain MR images with minimal artifacts and distortions using titanium T&O. We subsequently performed phantom studies to determine the levels of artifacts and distortions in both titanium applicators. We also verified the levels of artifacts on *in vivo* MR images of T&O patient cases. We discuss artifacts and distortions in the context of MRI-guided BT treatment planning when using a titanium applicator.

METHODS AND MATERIALS

Two titanium applicators: T&O and T&R

Titanium Fletcher-Suit-Delclos-style (FSD) T&O and titanium T&R were examined (Varian Medical Systems, Charlottesville, VA) (Fig. 1). In their intrauterine section, they have an outer diameter of <3.2 mm and an inner diameter of <2.35 mm. The ovoid cap of 3 cm without lead shielding was attached to both the titanium ovoids and ring.

Quality assurance phantoms for MRI-guided BT

The dedicated phantoms for each titanium T&O and T&R were developed to suspend an applicator and to provide a reference for quantifying the image distortion, based upon the literature (1, 9, 10). Four different reference rods were designed to be located as a function of the distance from a tandem (Figs. 1A and 1D) at 1, 1.5, 2, and 2.5 cm. Both phantoms were designed for the T&O or T&R to be positioned in intrinsic brachytherapy-eye-view (BEV), *i.e.,* the scanning orientation of axial images is orthogonal to the axis of the intrauterine tandem (Fig. 3 in Ref. 10). In addition, quality assurance (QA) procedures for a BT treatment planning system using three-dimensional (3D) images, based on the guideline (Chapter 9 in Ref . 11), were also accounted for. These include the following: (*1*) 3D image datasets' transfer integrity, (*2*) 3D image datasets' geometric accuracy, (*3*) source-reconstruction accuracy comparisons among orthogonal radiographs, CT, and MRI. A copper sulphate solution (1.5 g/l $CuSO_4$) was used as a contrast medium in the QA phantoms to reduce longitudinal relaxation time (T1) and to keep repetition time (TR) to a minimum (9). Comprehensive verifications of image quality in 3.0-Tesla MRI are beyond the scope of this study and were reviewed and discussed in other diagnostic MRI studies (7, 12–14).