Quantitative analysis and quality assurance of gynecological brachytherapy applicators using radiochromic film dosimetry

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PURPOSE

We present a QA methodology that includes quantitative analysis of the ^{192}Ir HDR source first dwell position within the applicator structure and its coincidence with the x-ray marker.

METHODS

Sixty-four different applicator sets with corresponding x-ray markers were tested including the Venezia, Utrecht, Fletcher, cylinder, multichannel cylinder, tandem and ring sets. Each set of applicators was fixed to a 5" by 8" piece of EBT3, XRQA2 or RTQA2 radiochromic films. The x-ray markers were inserted into the applicators and imaged using both x-rays and HDR source post markers removal. Four ball bearings (BBs) and ink-dots were placed at each corner of the film prior to imaging to allow for accurate quantitative analysis. The film was scanned with an EPSON 12000XL flatbed scanner at 254 dpi resolution using reflection (XRQA2, RTQA2) or transmission (EBT3) modes. The film image was registered to the x-ray image based on an affine four-points registration. An in-house developed tracking algorithm was utilized for automatic position and orientation assessment of the source and x-ray markers coordinates using blob analysis of iso-dose lines. For film exposures, optimum Ci·sec nomograms were generated for each film model to obtain adequate film exposure.

RESULTS

Figure 1A shows a typical setup using this method where four registration BBs (highlighted in yellow) are fixed to the film corners and the applicators are tightly taped on the film. On the other side of the film, ink-dots (highlighted in blue) are drawn to mark the BBs (Figure 1B). The setup is exposed to x-rays first where the BBs (highlighted in red) and the x-ray markers are visible in the x-ray image (Figure 1C). The inkdots and BBs are then registered as seen in Figure 1D which shows an example of the images overlay. The advantage of this method is that the contrast features of each image can be enhanced separately. It is of note this method allowed source tracking on the film because the distribution is not hindered by the applicator presence.

Source position accuracy for all applicators was found to be (0.10 ± 0.39) mm in the direction of source trajectory. The algorithm was able to detect and quantify lateral displacement of the source with respect to the x-ray marker position; this was not the case with a standard qualitative QA technique. XRQA2 film showed minimum fiducial registration error since the BB shadow on the film could be used for registration instead of the inkdots. Figure 1E demonstrates this method for different applicator models. Figure 1F shows a histogram of all displacement components in the source extension direction. The Ci·sec nomogram to give a specific dose has the form (Ci·sec $=88.2 \times \text{dose(Gy)} \times \text{distance}^2\text{(cm}^2\text{)}$), where the distance is between the source and the film. A 3 Gy dose gave adequate color for the analysis using all film models (XRQA2, EBT3, RTQA2).

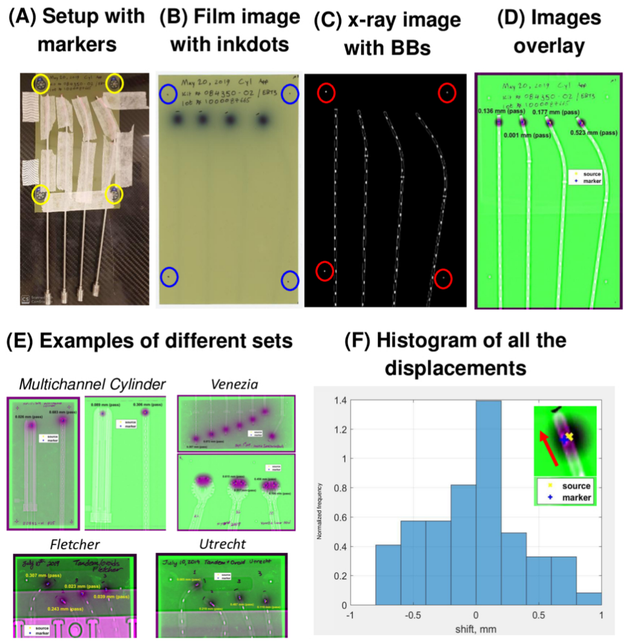

Figure 1: Demonstration of applicator QA with radiochromic film dosimetry and source tracking. (A) applicators attached to the film with inkdots/BBs on the corners, (B) post exposure image highlighting inkdots, (C) x-ray image highlighting registration BBs, (D) image overlay and application of source/marker auto tracking, € visual QA examples of different applicator sets, and (F) histogram of all displacements (total of 64 applicators, 0.10 ± 0.39 mm)

DISCUSSION

This work introduced quantification to the applicator/x-ray marker quality assurance test that is typically based on qualitative evaluation. This method takes advantage of the film high resolution to provide accurate source tracking based on isodose line centroid analysis which does not require a linear relationship between the film response and the dose. It requires scanning of the film for its implementation, but it enables accurate evaluation of source/x-ray marker coincidence within the applicator. Also, the method is more forgiving than conventional QA in case the films were overexposed since the markers are captured with x-rays anyways. Additionally, with contrast enhancement, the method was able to analyze MR/CT compatible markers in addition to conventional x-ray markers.

CONCLUSIONS

The proposed method is capable of quick and quantitative analysis of the HDR source first dwell position. The method was used clinically to improve current QA of gynecological brachytherapy applicators.

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