Detection of Errors in HDR Brachytherapy With an in Vivo Dosimeter With Real-Time Positional Tracking Information

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Introduction:

This study presents an approach where a plastic scintillation detector is coupled to an electromagnetic (EM) sensor (having sub-mm positional accuracy) for real-time tracking of the dosimeter position. Knowing the detector's position at all time can differentiate error causes in ambiguous situation (e.g. shift in detector-source distance from either a moving detector or moving applicator/catheter/indexer' length). Positioning and timing accuracy is of critical importance for high dose rate (HDR) brachytherapy because it delivers large doses of radiation in a reduced number of visits. During treatment, indicators of errors can be dwell-time, dwell-position and dose.

Purpose:

Present an in vivo dosimeter with real-time positional information for error detection in brachytherapy.

Materials and Methods:

Detector details

- A plastic scintillation dosimeter prototype was coupled with an 5DOF electromagnetic (EM) sensor read by the Aurora V3 system (NDI, Canada).
- 3 mm long BCF-60 of 0.5 mm diameter (Saint-Gobain Crystals).
- EM sensor was 4 mm long and had a 0.4 mm diameter; it was placed at the dosimeter's tip with a distance of 2 cm from the scintillator.
- The detector construction is detailed on Fig.1A. Fig.1B shows the first 14 cm from the tip of the detector which is inside a peek tubing for better resistance to bending or any kind of pressure [1]. The EM sensor cable is twisted around the optic fiber and fixed with UV glue (Fig.1C).

Data acquisition details

- EMT sensor position sampling rate was 40/s.
- Dosimeter sampled at 100 000/s using a Hamamatsu photomultiplier tube (H10722) connected to a NI-DAQ data acquisition board (NI USB-6289 M Series, National Instruments, Austin, TX, USA).

Analysis details

- Dose rate was converted to dosimeter-source distance and the position of the dosimeter deconvolved using EM.
- Dwell time was calculated with the dose rate by a gradient search.
- All measurements were performed with an afterloader unit (Flexitron-Elekta AB, Sweden) to determine both positioning and dwell time precision.
- Indexer length errors (along the insertion axis) between 1 to 15mm were simulated by moving the source. The measured dose difference was converted to a shift in mm and was compared to the simulated errors.
- Catheters were shifted perpendicular to their insertion axis between 1 to 10 mm using a robotic arm (Meca500, Mecademic, Montreal).
- The detector was also shifted by 5 mm (corresponding to a neighboring hole in HDR template). Data were analyzed with and without the information from EMT in order to compare the false positive rate.

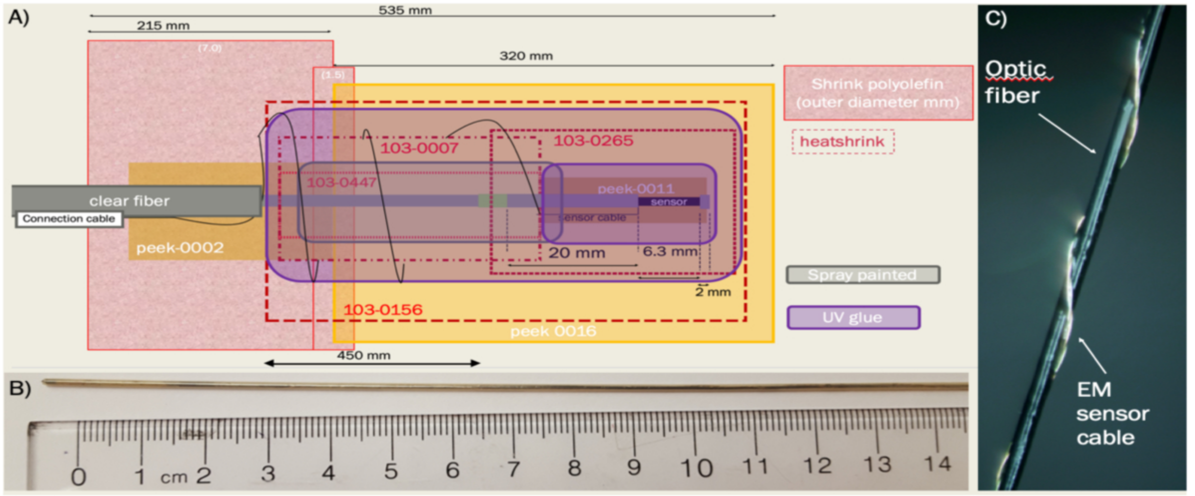

Fig 1. Plastic scintillation dosimeter prototype. A) Detailed construction of the dosimeter. B) Optical fiber with EM cable wrap around it. C) Dosimeter tip (320 mm).

Results:

Average difference between introduced indexer errors and measurements is smaller for source-dosimeter distance under 2 cm (0.2 ±0.1 mm) vs. under 4 cm (0.7±0.4 mm) (Fig. 2). All indexer's errors higher than 1 (3) mm at distances under 2 (4) cm were detected experimentally.

The mean absolute errors for dwell-time extraction is 0.4±0.1 s. Errors can be detected only with measured changes in dwell time, for instance resulting in catheter swap [2]. Finally, dose rate measurement lies within 3.6% from TG-43 up to a distance of 10 cm from the source.

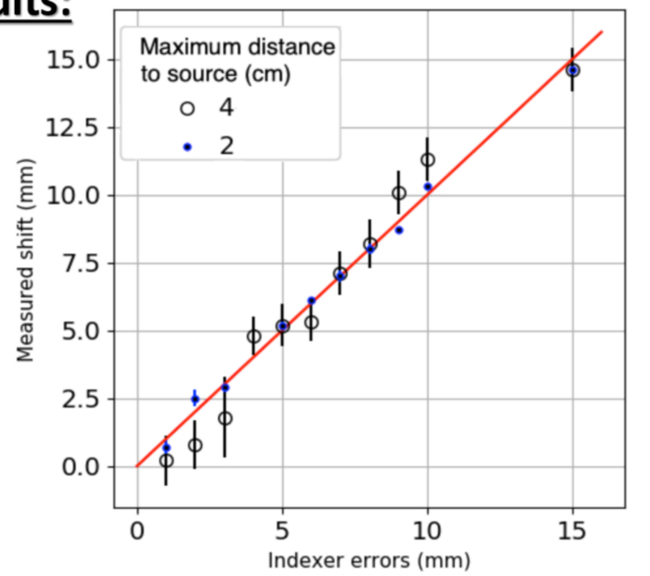

Fig. 2 Measured shift for different indexer errors. Measurement were performed at increasing distances from the source up to 2 cm and 4 cm. Error bars corresponds to one standard deviation. The red line shows the ideal situation where all measured shifts equal the expected ones.

Converting dose to detector-to-source distance has an average error of 1.1 ± 0.5 mm and a maximum error of 1.7 mm for a source-dosimeter distance of 10 cm.

Using the information given by the EMT tracker on the detector reduces false positive rates occurring because of detector displacement (Fig. 3A). In addition, Fig 3B shows that the catheter displacement detection true positive rate is higher (by 6%) for shifts smaller than 3 mm when EMT is used to track the dosimeter position.

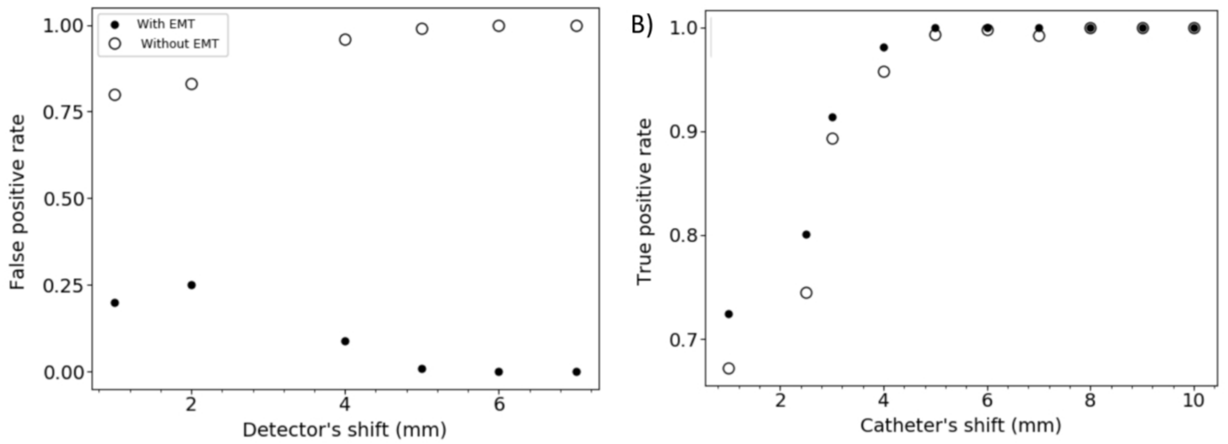

Fig. 3 Error detection comparison with and without electromagnetic tracking .
A) False positive rate as a function of detector's shift (only the detector was moved);
B) True positive rate as a function of catheter's perpendicular shift.

Conclusions:

This work demonstrates that integrating an EM tracking sensor to an energy independent plastic scintillation dosimeter can be used to detect indexer's length or catheter shift errors by removing the ambiguity on the detector positioning.

References

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2. Claus E. Andersen, Søren Kynde Nielsen, Jacob Christian Lindegaard, Kari Tanderup. Time-resolved in vivo luminescence dosimetry for online error detection in pulsed dose-rate brachytherapy. Medical Physics, 36(11):5033–5043, 2009.

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