OC-0277 Multibody dynamic modelling of the behaviour of flexible cervical cancer brachytherapy instruments

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OC-0277 Multibody dynamic modelling of the behaviour of flexible cervical cancer brachytherapy instruments

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Purpose or Objective
The steep dose gradients in cervical cancer HDR brachytherapy (BT) necessitate a thorough understanding of the behaviour of the source cable in applicator channels. Whereas multiple studies have quantified source positioning accuracy, the influence of applicator design parameters on source cable behaviour has not been investigated. Moreover, it is also unknown how these design parameters impinge on the ease and accuracy of catheter insertions in hybrid intracavitary-interstitial (IC/IS) applicators. The purpose of this study is to develop and validate comprehensible computer models to simulate: (1) HDR BT source paths, and (2) insertion forces of catheters in curved applicator channels. These models can aid the development of novel (3D-printed) BT applicators and improve the accuracy of source path models in current applicator libraries.

Materials and Methods
Two types of interactions were modelled: (1) Flexitron source cable (Elekta, Stockholm, Sweden) positioning in CT/MR ring applicators (Elekta, diameters: Ø26, Ø30 and Ø34 mm, angles: 45° and 60°), and (2) ProGuide 6F catheter with obturator (Elekta) insertion in S-shaped channels with varying design parameters (curvature, geometric torsion, and clearance). Instruments were modelled as an interconnected series of flexible beam elements or rigid beam elements connected through revolute joints with springs. For evaluating the source cable models, the simulated source paths were compared with centreline data and the source paths provided by the manufacturer. Predicted catheter insertion forces were compared with force measurements in dedicated templates, produced with common 3D-printing methods for medical devices: digital light processing (DLP) and selective laser sintering (SLS).

Results
The simulations illustrate curving and snaking of the BT source cable in applicator channels. Maximum differences between dwell positions of the simulated source path and centreline data were observed for the most distal dwell position and varied between 4.0-6.4 mm in ring applicators of different sizes. Simulated paths were in closer agreement with manufacturer-specified paths, with maximum differences of 0.7-1.4 mm in the distal dwell position (Figure 1). Insertion force simulation results for BT catheters were in close agreement with the experimental results for all channel design parameters (Figure 2), and predicted peak forces were within 25% accuracy. Accuracy of simulated force characteristics can be improved by incorporating friction coefficient measurements.

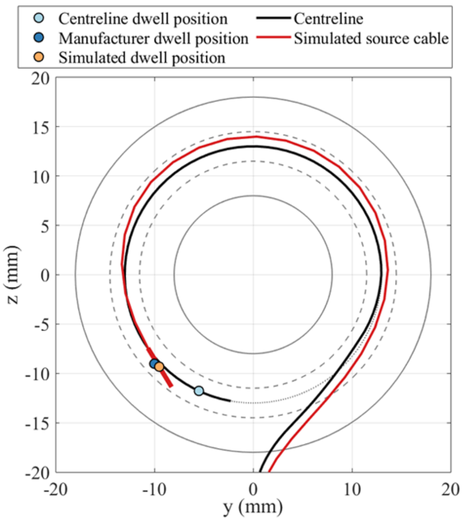

Figure 1: Two-dimensional projection of the simulated source cable when inserted to the most distal dwell position in a modelled 26 mm, 45° CT/MR ring applicator (Elekta), with corresponding distal dwell positions on the digitised centreline and source path provided by the manufacturer. Dashed and solid grey lines indicate the lumen and outline of the applicator respectively.

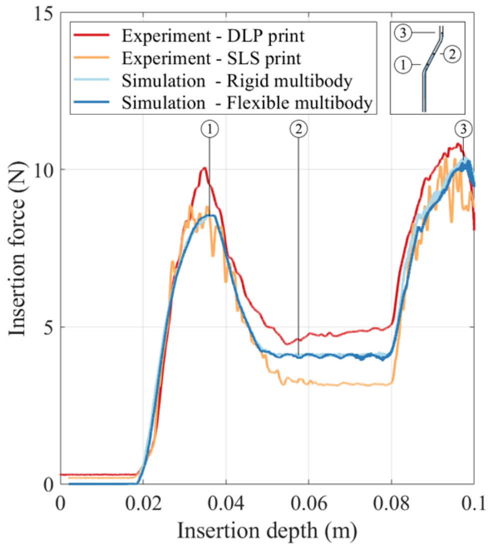

Figure 2: Comparison of simulated and experimentally established insertion depth-force characteristics of a ProGuideTM 6F catheter and obturator in a planar S-shaped channel. The channel has radii of 35 mm and a lumen diameter of 2.6 mm.

Conclusion

The developed models show promising results in predicting the behaviour of flexible instruments in BT applicators. Insights from these models can aid novel applicator design with improved motion and force transmission of BT instruments. Moreover, the presented methodology may be extended to study other applicator geometries, flexible instruments - including different source cables, marker wires or sensors-, and afterloading techniques.

OC-0278 First clinical results of integrated EMT for quantification of positional deviations in cervix BT

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Purpose or Objective

For correct dose delivery in cervix brachytherapy (BT) the dwell positions and times need to precisely correspond to the treatment plan. Correspondence of the actual applicator and needle positions with the MRI/CT-based treatment plan is therefore essential. Positional deviations however might occur due to applicator and/or needle shifts, transfer tube swaps, anatomical changes or reconstruction uncertainties. Electromagnetic tracking (EMT) has been proposed for detection of such errors and uncertainties. The feasibility of EMT using a prototype of a hybrid EMT/BT system, i.e. a Flexitron afterloader with an EMT sensor integrated in the check cable (Elekta, Veenendaal) has previously been demonstrated by phantom experiments in typical clinical BT environments. An accuracy of less than a millimeter was found in 6F interstitial plastic needles. The purpose of this study is to prospectively analyze the feasibility of this system to detect treatment errors and reconstruction uncertainties in cervix HDR BT patients.

Materials and Methods

Twenty cervix patients, treated with three or four HDR BT fractions using an intracavitary/interstitial applicator as part of their treatment, were included in a prospective study, simulating a workflow with EMT-based treatment verification. EMT measurements, scheduled before dose delivery in one to three BT fractions per patient, were performed using the hybrid EMT/BT afterloader by automatically moving the EMT sensor through all needles in the implant according to a predefined MRI- or CT-based treatment plan. Dose delivery was performed afterwards using our clinical afterloader, ensuring that the clinical treatment was not affected by the EMT experiments. The intracavitary channels were discarded in this study as our phantom study showed unacceptable deviations. The residual errors, i.e., the Euclidean distances between the registered EMT measured and planned dwell positions, were calculated.

Results

Data sets from 37 fractions were available for analysis. In three data sets (3, 23 and 28) a discrepancy between the registered EMT and planned dwell positions, e.g. a channel swap (fig. 1a), was detected. The increased difficulty in needle reconstruction based on MRI scans compared to CT scans was reflected by a significant difference in mean residual error ($p<0.001$), i.e. 0.90 mm and 0.68 mm for MRI-based and CT-based reconstruction, respectively. Moreover, outliers were detected in 5 data sets (20, 22, 32, 33 and 34), i.e., a single needle with a high residual error. These datasets were all planned using MRI and contained ≥ 6 needles, again suggesting reduced reconstruction accuracy for MRI (fig. 1b). The results are summarized in figure 2.