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Gynecological brachytherapy with Elekta microSelectron V3 afterloading system

A method for determination of actual dwell positions in CT/MR ring applicators

Abstract: *Objective:* For commissioning of source path models for ring tubes of Nucletron (now Elekta) CT/MR ring applicators, a method was established using a source position simulator (SPS) and a CT scanner. *Methods:* An acrylic glass support for ring tubes was constructed serving as defined coordinate system. With SPS, 40 positions were set in the ring in steps of 2.5mm from proximal to distal direction. In each position a CT-series was taken with ring plane inside scan plane using a GE Optima 580 scanner (slice width 0.625mm). Evaluation was done in multiplanar reconstruction mode under display settings revealing dummy source shape. With a 3D-cursor dwell position coordinate (center of Ir-192 core) was determined. Measurements were validated by film autoradiography in selected positions. Four rings were investigated: 60° Φ26, 45° Φ26, 60° Φ30, and 45° Φ30 with figures denoting angle between ring plane and stem and ring diameter in mm. *Results:* The method is feasible to reconstruct source dwell positions with an overall accuracy of ±0.3mm. Detected coordinates are consistent and in excellent agreement with those obtained by autoradiography. Comparison with Elekta's source path models, however, revealed mean deviations of up to 3.5mm. *Discussion:* It is advisable to measure individual source paths and have them added to the data base of the treatment planning system.

Keywords: brachytherapy, afterloading, CT/MR ring applicator, source path, dwell position, accuracy.

https://doi.org/10.1515/cdbme-2017-0137

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1 Introduction

In gynecological remote afterloading brachytherapy, MRI-based treatment planning is recommended [1] and increasingly used in clinical practice. Reconstruction of applicators hardly visible in MRI scans remains challenging.

The CT/MR ring applicator by Elekta offers the possibility to insert a thin water hose for source path visualization during MRI. Because of the necessary lumen of 3mm the channel cannot offer close guidance to afterloading wire (0.9 mm diameter) so that in ring tube, actual dwell positions can deviate substantially from theoretical values on channel midline [2, 3]. Therefore Elekta provides ring tubes with measured source paths. These are meant to be commissioned on-site, but no feasible method is indicated for this task. Film autoradiography is not appropriate, as neighbouring dwell positions cannot be resolved due to large distance between source and film. Furthermore, autoradiography can only be applied with 2-dimensional source paths. Therefore an alternative, fully 3-dimensional method for source position determination was established using an SPS and a CT scanner. The CT method was validated by autoradiography at selected single positions.

2 Method

Four ring tubes belonging to Elekta's CT/MR ring applicator sets 60° and 45° were examined: 60° Φ26, 60° Φ30, 45° Φ26, and 45° Φ30 with figures denoting angle between ring plane stem and ring diameter in mm (measured between channel midlines on both sides).

An acrylic glass support (see **Figure 1a, 1b**) was constructed serving as defined coordinate system for all ring tubes. By means of a conical pin the ring is pressed with its "therapeutic" side against a plate and simultaneously centered in xy-plane. Negative y-direction is defined by a lead for the ring stem. The coordinate system is visualized in CT

examination (with ring plane parallel to scan plane) by hollow plastic pins screwed to the plate.

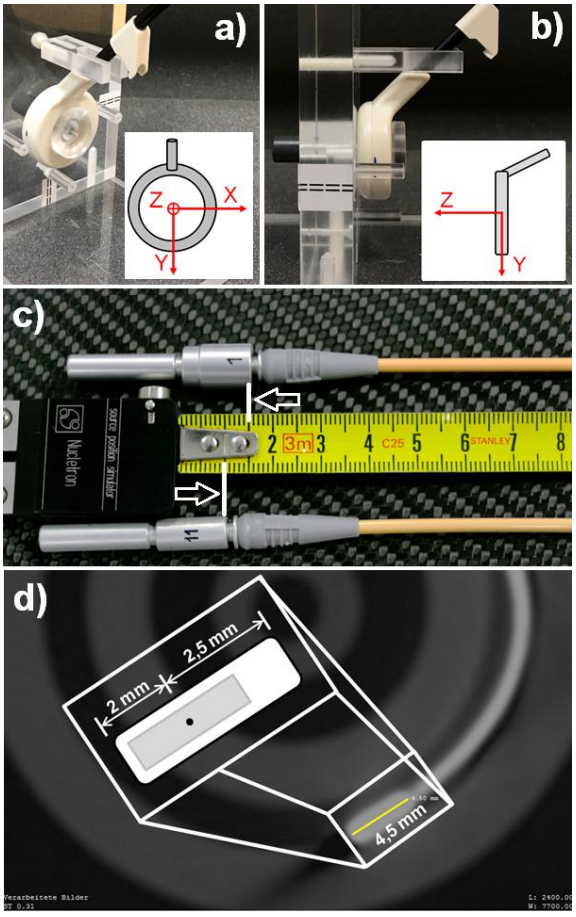

Figure 1: a), b): coordinate system for measurements; c): SPS (left image side) with ring transfer tube 1 and approved transfer tube 11 alongside, indicating inserted position; d) dwell position determination on CT-image

2.1 CT method

The ring is connected via transfer tube to SPS. As this device is not calibrated for use with a ring transfer tube, the connector does not snap in. Comparison with an approved transfer tube shows that the ring tube connector protrudes 5mm further from SPS. These 5mm have to be added to all SPS-lengths intended for ring tubes (see **Figure 1c**; at afterloader indexer plate both connectors protrude by the same distance). Correct calibration of SPS was checked with a source position ruler and the approved transfer tube prior to measurements.

For any of the 4 rings to be examined, 40 source positions were simulated starting at proximal end and shifting only in distal direction with step size 2.5mm as performed by the afterloader (Elekta microSelectron V3). In each position a CT series was taken with a GE Optima 580 CT scanner (in helical mode, pitch factor 0.562, 140kV, slice width 0.625mm, slice distance 0.315mm, convolutional kernel "Chest"), which was evaluated in multiplanar reconstruction mode under suitable display settings revealing dummy source shape. With a 3D-cursor, the dwell position coordinate (center of Ir-192 core of mHDR v2 source as described in [4]) was determined as follows: A line of 4.5mm (length of source capsule) was drawn on CT image along middle axis of dummy source. 3D-cursor was positioned 2mm behind the front end of this line (see **Figure 1d**).

The ring with smallest curvature and largest angle between ring plane and stem (60° Φ 26) was chosen to examine the reproducibility of source position determination with this method. The whole measurement (from position 40 to position 1) was repeated 3 times and mean and standard deviation (SD) of detected coordinates were calculated. Additionally, the same study (with 3 repetitions) was undertaken with positioning procedure inverted (from distal to proximal). For the other 3 rings only 1 measuring run (from proximal to distal) was performed.

Determined dwell position coordinates were compared to those measured by Elekta [3], which were extracted from treatment planning system (TPS) Oncentra® Brachy v4.5 together with the coordinates of channel midline. Elekta default data exist for the 30 (34) most distal positions in small (large) rings.

To check consistency of measured data sets, the distance between neighbouring dwell positions (step size) was calculated. The sum total of all steps from position 1 to 30 (34) was then compared to theoretical source path lengths 7.25cm (8.25cm).

2.2 Autoradiography

The same ring support was used for autoradiography at 5 selected positions in ring plane. Gafchromic® EBT film sheets were placed on the acrylic plate underneath the ring. Consistent film positioning relative to coordinate system was accomplished using incisions in the film sheets and corresponding marks on the plate. Four films were exposed for each ring. Evaluation was done by setting a dot into center of film blackening and determining dot coordinates with millimeter paper. For all coordinates mean values and SD were calculated.

Correct positioning of afterloading source at the intended positions was checked autoradiographically prior to measurements by using a measuring film in the source position ruler.

3 Results

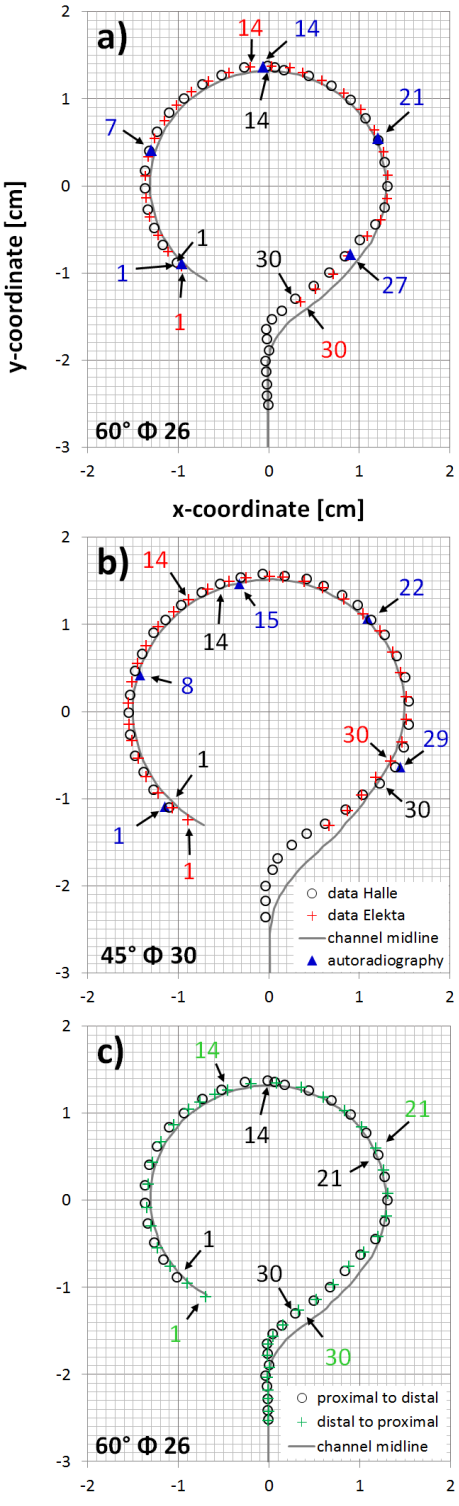

Figure 2: CT-measured data together with data from autoradiography compared to Elekta data in ring with a) best and b) worst coincidence; c): comparison of CT-measured data with different direction of positioning.

3.1 Dwell positions from CT method

3.1.1 Accuracy of dwell position determination

From repeat evaluations of same dwell position, accuracy of position determination with CT method was estimated as ±0.3mm in all directions; positioning accuracy of SPS is specified with ±0.5mm. Reproducibility of coordinates with repeat positioning series in ring 60° Φ 26 was high. Maximum SD of measured coordinates was 0.3mm in ring plane and 0.7mm perpendicular to it.

3.1.2 Conformance with Elekta's source path

Conformance with Elekta's overall source path was good for all examined rings. Actual dwell positions, however, did not coincide well in all cases. **Figure 2** shows the 2 rings with best (**a**) and worst (**b**) accordance.

3.1.3 Distance from Elekta's dwell positions

Mean distance of measured coordinates from values provided by Elekta was 1.1mm (1.7mm, 2.9mm, and 3.5mm) in ring 60° Φ26 (45° Φ26, 60° Φ30, and 45° Φ30). Considering specified positioning accuracy of ±2mm for the afterloader, this result appears acceptable for the small rings, but unsatisfactory concerning the large rings.

3.1.4 Step sizes and source path length

Mean step size was 2.4mm in all measured rings when positioning the dummy source from proximal to distal. This is in accordance with Elekta-measured data, the value, however, being smaller than nominal step size of afterloader (2.5mm).

Table 1: percentage deviation of measured source path lengths from expected values 7.25cm (8.25cm) in small (large) rings. Uncertainty of path length determination in this study is about 0.7%.

Ring	Data Halle	Data Elekta
60° Φ26	-3.8%	-2.4%
45° Φ26	-3.3%	-3.6%
60° Φ30	-2.6%	-3.0%
45° Φ30	-2.1%	-3.6%

The percentage deviation of measured total path lengths from expected values is shown in **Table 1**. All path lengths were smaller than expected. This means that due to friction and

play of afterloading wire in the ring, a shift of the wire does not necessarily move the dummy source by the same amount. This effect increased with increasing ring curvature and increasing angle between ring plane and stem and is accordingly described in [3]. The Elekta data, however, do not exhibit this dependence.

3.1.5 Difference between positioning from proximal and positioning from distal direction

There was a clear difference in the measured dwell positions depending on the direction from which the dummy source was positioned (see **Figure 2c**). In ring stem, dwell positions coincided well. Going further proximal, the difference between dwell positions increased from 0.5mm to 3.9mm at the lumen tip. At positions 13 and 14 extremely large differences of 3.9 and 4.8mm occurred. Only with positioning from distal direction lumen tip was reached and step sizes appeared more uniform (SD 0.4mm) compared to positioning from proximal direction (SD 0.5mm).

These findings prove that the source undergoes a hysteresis loop and that it is not recommendable for coordinate measurement to position the source once from proximal and once from distal direction and take the average.

3.2 Dwell positions from autoradiography

Accuracy of coordinate determination with described method of film positioning and evaluation is estimated to ±1mm.

Table 2: average distance of 5 coordinates determined autoradiographically to those indicated by Elekta and to CT-measured points respectively (mean value out of 5 distances ± SD)

Ring	Dist. to Elekta coordinates [mm]	Dist. to CT-measured coordinates [mm]
60° Φ26	0.8 ± 0.8	0.4 ± 0.8
45° Φ26	1.7 ± 0.6	0.6 ± 0.6
60° Φ30	2.4 ± 0.5	0.6 ± 0.6
45° Φ30	3.3 ± 0.5	0.6 ± 0.5

There was an excellent agreement between the five coordinates measured autoradiographically and those obtained by CT-method (see **Figure 2a** and **2b**). In **Table 2** the average distance to dwell positions determined with CT-method (mean of five distances ± SD) is shown. It was below 1mm for all 4 rings.

4 Discussion

Results from two alternative methods for measuring source dwell positions were in excellent agreement and consistent to geometric considerations formulated in [2] and [3]: Friction and play of afterloading wire in the ring channel cause irregular step sizes and increasing deviations from expected dwell positions on channel midline with increasing ring curvature and increasing angle between ring plane and stem. Therefore the largest (least) problems would be expected for ring 60° Φ26 (45° Φ30) and it is surprising that in ring 60° Φ26 of all rings the Elekta–provided source paths show the closest agreement to the findings of this study and in 45° Φ30 the largest deviations, which are with 3.9mm on average too large compared to specified positioning tolerance of ±2mm for the afterloading device.

In any case it is advisable for users not to only rely on the source path models provided by Elekta, but to perform their own measurements and have them added to the database of the TPS. The present study can serve as a guideline how to accomplish this task in a clinical setting.

Author's Statement

Research funding: The authors state no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent is not applicable. Ethical approval: The conducted research is not related to either human or animals use.

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