Radiation Dose Reduction in OAR by using the Fletcher CT/MR Shielded Applicator and Oncentra® Brachy Advanced Collapsed cone Engine

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Summary

• The Fletcher CT/MR Shielded Applicator significantly reduces radiation dose to rectum, bladder, and sigmoid

• The most significant reductions are shown in the rectum

• Oncentra Brachy ACE allows for a more accurate calculation of the dose distribution with shielded applicators
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1. Introduction

This white paper describes the clinical workflow for the Fletcher CT/MR Shielded Applicator, including CT and MR imaging and treatment planning using the Oncentra Brachy treatment planning system. The presented workflow serves as an example to learn the concept and how to implement a similar workflow in the user’s clinic. The planning workflow presented here also provides initial dosimetric results using the recently introduced model-based dose calculation algorithm, ACE, following the AAPM TG-186 guidelines\(^1\) and in comparison with current standard AAPM TG-43 dose calculation methods.\(^2-3\)

2. The Benefits of the Fletcher CT/MR Shielded Applicator in Combination with Oncentra Brachy ACE

a. Fletcher CT/MR Shielded Applicator with Movable Shields

Intracavitary brachytherapy (ICBT) is an essential element of definitive radiation therapy for cervical cancer providing a high rate of local control and survival for women with locally advanced disease.\(^4-5\) With proper placement, ICBT delivers a high dose of radiation to the cervix and adjacent tissues while minimizing the dose to healthy tissues.\(^6\) However, with ICBT it is often necessary to irradiate the bladder, rectum, and sigmoid to organ tolerance, which can result in late complications in these organs.\(^7-8\)

Standard Fletcher-style vaginal colpostats have integrated tungsten-alloy shields positioned anterior-medially and posterior-medially within the ovoid, reducing the radiation dose to the adjacent bladder and rectum by as much as 25%.\(^9-10\) Unfortunately, on computed tomography (CT) images these shields produce significant artifacts that obscure the interface of the bladder, rectum, and sigmoid with the cervix. Because these interfaces typically receive the highest dose of radiation, it is critical to accurately evaluate the dose delivered in these regions. Artifact-free CT or MR scans can be used to generate three-dimensional brachytherapy treatment plans to evaluate dose-volume parameters of normal tissues.\(^11-12\)

The current commercially available CT- and MR-compatible brachytherapy applicators for treatment of cervical cancer were designed without the ovoid shields to allow high-quality images for brachytherapy treatment planning, yet eliminating a key advantage of Fletcher-style applicators.\(^13\) To address this limitation, Elekta designed a novel CT/MR-compatible applicator with movable shields called the Fletcher CT/MR Shielded Applicator.\(^14-15\) This novel applicator mitigates CT image artifact by moving the shields during CT acquisition, hence the X-ray beam does not pass through the shields. Furthermore, additional improvements on several aspects of the Fletcher-Williamson applicator were made to make it easier to insert and place within the patient anatomy.

Example of CT artifacts produced due to tungsten shields in a non-CT-compatible applicator. Organs-at-risk are difficult to see and delineate.
b. **ACE Dosimetry Optimization**

Recently, a collapsed cone convolution (CCC) algorithm has been developed specifically for performing accurate and rapid dose calculations for brachytherapy in response to AAPM TG-186 recommendations to allow users to move beyond the TG-43 approach for calculation of absorbed dose. Released under the name ACE, which stands for Advanced Collapsed cone Engine, it accounts for applicator materials, tissue heterogeneities, and patient boundaries. There have been some studies on the details of CCC. \(^{19-21}\) Recent reports on commission and quality assurance of this advanced dose algorithm have been reported in the literature.\(^1\)

c. **The Powerful Combination of Both Technologies**

The clinical integration of the Fletcher CT/MR Shielded Applicator and ACE dose calculation algorithm enables clinicians to seamlessly calculate the dose perturbation due to the rectal and bladder tungsten shields per AAPM TG-186 recommendations\(^{1,17}\) using CT images with the highest fidelity mitigating CT image artifacts.

### 3. CT Imaging Workflow

The Fletcher CT/MR Shielded Applicator employs a unique CT imaging protocol that must be followed to gain the advantages of this type of applicator. Below is an overall description of how users should perform CT imaging. Modification of this procedure can be created based on the model and type of CT scanner used and site-specific protocols. For MR, the imaging workflow is similar to current pelvic MR protocols and an example is described below.

The X-ray markers — listed in the Fletcher CT/MR Shielded Applicator user manual — are to be used for CT imaging of the intrauterine and ovoid tubes of the applicator. The CT bore needs to be tilted 20-25 degrees with respect to the table surface toward the patient’s head to obtain oblique images that do not pass through the shield. The gantry bore tilt is rotated to the maximum angle possible, which permits clearance of the patient comfortably through the CT bore during the image acquisition. All images will be acquired using the same scanning parameters. One lateral scout view should be taken prior to CT imaging to determine patient positioning, gantry tilt and slice locations.

During scanning, a "step-and-shoot" technique should be utilized as follows: the rectal shield (Posterior) is docked at its proximal end of travel, adjacent to the bladder shield (Anterior), and scans are taken to the midpoint of the ovoid (Step 1). The scanner is then paused, both the rectal and bladder shields are moved to the distal end of travel, and the scan is then resumed and completed (Step 2).

In Step 3, the bladder shield is placed back in its default position (Anterior) and both shields are locked in position and a CT scout is taken to verify final position.
1. Set-up the patient in the Feet-First-Supine position (or Head-First-Supine position).

2. With the default CT scanner gantry angle, i.e. with 0° tilt, slide the patient through the CT bore to the most superior CT slice position desired (to include the lower abdominal region).

3. Tilt the scanner toward the patient's head to determine the maximum tilt angle that still allows patient movement through the CT bore.

4. Record the scanner tilt angle.

5. Tilt the scanner back to 0° (because of Scout Scan).

6. Move the couch (patient) to the most inferior position.

7. Remove the sterilization caps from the two ovoid tubes. To unlock, rotate the sterilization caps counterclockwise.

8. For both ovoid tubes (1+2), unlock the ring of the Posterior shield ("P") by rotating counter clockwise. Slide the ring of the Posterior shield towards the Anterior shield ("A" position).

9. Leave the CT room.
CT Imaging for Treatment Planning Data

10. Perform a Scout Scan (quick scan) with both shields at "A" for both ovoid tubes and scanner at "0°" angle (step 5).

11. Enter the recorded scanner tilt angle in the control system of the scanner (obtained from instruction step 4).

12. Determine the SUPERIOR scan extent. Note: The most inferior edge of the scan should be near the shield edge as shown in the diagram.

13. Ensure the SUPERIOR scan encompasses the patient anatomy.

14. Record the Start and End positions for the SUPERIOR scan. Enter the recorded End position from the SUPERIOR scan into the Start position of the INFERIOR scan. Note that the SUPERIOR and INFERIOR scans have no overlap or gap.

15. Now the correct scan parameters are entered and the couch is moved automatically to the initial position of the SUPERIOR scan.

16. Start the CT acquisition of the SUPERIOR scan.

17. After the SUPERIOR scan is done, enter the room.

   1) Unlock the ring of the Anterior shield of both tubes.

   2) Move the shields of both ovoid tubes to the "P" position.

18. Leave the CT room.

19. Start next CT acquisition of the INFERIOR scan.

20. Follow the instructions of the control system and finish the scan.

21. After the scan is done, enter the CT room. Slide the Anterior shield of both ovoid tubes toward "A". Lock the ring of the Anterior and Posterior shields. For both ovoid tubes shields should be at "A" and "P".

22. Leave the CT room.

Verification Scan

23. Tilt the CT scanner back to 0°.

24. Move the couch (patient) back to the most inferior position.

25. Make a Scout Scan (quick scan) to verify the position of the shields of the ovoid tubes. Both ovoid tubes (1+2) have shielding in Treatment Position; "A" ←→ "P". The distance between the two shields should be 19.5 ± 1 mm.
Expected Qualitative Results for CT Imaging with the Fletcher CT/MR Shielded Applicator Set

Examples of axial CT images are shown above. The axial images obtained with the shields shifted are shown in the right panel. The axial images obtained with the shields in the treatment position for the same patients are shown in the left panel. High- and low-density streak artifacts can be appreciated within the bladder and rectum. Contours of the bladder (yellow) and rectum (blue) were drawn using CT images with shifted shields (no artifact, right panel) and rigid image registration performed to copy them onto the CT images acquired with shields in treatment position (left panel).

For more details and quantitative assessment of the CT artifacts, see reference 18.
4. MR Imaging Workflow
MR acquisition can be performed on a 1.5T or 3.0T scanner. MR compatibility of the applicator is verified and documented prior to placement of the patient in the scanner (see user manual Fletcher CT/MR Shielded applicator). Institutional MR imaging protocols should be followed.

At MD Anderson Cancer Center (Houston, TX), the images were obtained utilizing an 8-channel cardiac coil. High resolution T2 Fast Spin Echo (FR-FSE) images were obtained in the coronal plane (3mm contiguous slices/FOV 18-22 cm/ TR>3000/TE>100msecs). The coronal plane should be used to generate oblique sagittal and oblique axial images of the cervix and applicator – parallel and perpendicular to the applicator device within the cervix, respectively. Axial T2-weighted FR-FSE images of the entire pelvis should also be obtained at the end of the examination. Additionally, a T2 Axial Cube image with isotropic 1 mm voxels should also be obtained if needed. On the day of the implant, MRI images will be evaluated for adequate applicator position within the uterus and cervix to rule out any possible, if rare, major deviations in applicator placement such as uterine perforation. An example of a sagittal MRI image of applicator is shown. Note the excellent image quality with the tungsten shields.

5. Treatment Planning Workflow
The Oncentra Brachy treatment planning system is able to import the oblique CT data acquired in section 1 above. Using Anatomy Modeling, contour the organs-at-risk and target as usual. Remember to also create the external structure (Patient contour) since it is needed for the ACE calculation.

In the Brachy Planning module, the common planning steps are followed and the Fletcher CT/MR Shielded applicator is imported from the Applicator Library. It should be noted that the tandem and ovoid sizes inserted in the patient should be known and selected from the applicator library. See example below for a 45 degree tandem and 20 mm diameter ovoids for CT-based planning.
The same standard procedure should be followed for registering the applicator onto the patient anatomy (please also see the Fletcher CT/MR Shielded Applicator user manual). Planning should start using the TG-43 approach as recommended by AAPM TG-186. TG-186. An example of a plan is shown below.

Also, a plan generated using TG-186 (CCC) with “Standard” or “High Accuracy.”

The user can apply “Plan Analysis” to compare TG-43 and TG-186 results, as shown below; the impact of the shields is clearly shown to the rectum. Detailed dosimetry analysis and summary statistics for a cohort of GYN patients is provided below in section 6.2.
6. Dosimetric Comparisons

6.1 Basic Dosimetry / Physics

A basic ROI (Region of Interest) structure was created to characterize the shield's impact on a hypothetical cylindrical ROI near the rectal shields. The ROI was created using Oncentra ROI tools.

Below results show a single most distal source in each ovoid. A maximum dose reduction of 54% to the ROI structure was found using TG-186 relative to TG-43. Similar maximum dose reduction value is reported by Gifford et al using Monte Carlo and radiochromic film measurements.\(^{22}\)
Moreover, a typical ovoid loading of 4 dwells per ovoid was simulated using the same ROI. ROI 1 cc and 2 cc are about 35% lower in dose rate for TG-186 relative to TG-43 dose prediction.

Top panel: TG-43 Plan. Bottom panel: TG-186
6.2 Clinical Dosimetry Early Reports

Twelve patients undergoing definitive radiation therapy on a prospective protocol for stage ≥ IB2 cervical cancer, were treated with external beam radiation therapy followed by intracavitary pulsed dose rate brachytherapy (ICBT) with the Fletcher CT/MR Shielded Applicator for one of two insertions, at The University of Texas MD Anderson Cancer Center. (IRB Approved protocol 2012-0546 "3D Image-guided Intracavitary Brachytherapy Treatment Planning for Cervical Cancer using a Novel Shielded Applicator, PI: Klopp Ann). Each patient had a pelvic CT and MRI with the applicator in place. The applicator was then reconstructed on MR. The bladder, rectum, and sigmoid were contoured for all 12 patients and a high-risk clinical target volume (HR-CTV) was contoured for two of the patients.

An example of one case comparing the dose distributions between TG-43 and TG-186 algorithms from Oncentra Brachy is shown below.

Absolute dose difference around the ovoid is also depicted to indicate the large dose perturbation of the shields and the new Oncentra capability that enables accurate modeling of such perturbations.

Absolute dose difference (cGy) between TG-43 and TG-186 (TG43-TG186) as calculated using the Oncentra Brachy TPS around the Fletcher CT/MR Shielded Applicator. TG43 over prediction of dose behind the rectal and bladder shields is demonstrated.
It should be also noted that in this study there was no impact on dose delivered to tumor as expected since the shields do not impact the tumor. To demonstrate this, axial planes passing through ICRU A points (ART: Right A point, and ALT: Left A point). The isodose contours are shown below for both TG-43 and TG-186.

DVH parameters analyzed were: D2cc, D1cc, D0.1cc to bladder, rectum, and sigmoid as well D90 for the HR-CTV was calculated. A paired t-test was used to compare the above DVH parameters for plans using TG-43 and TG-186.
Table 1: Dose reduction to critical organs (n=12)

<table>
<thead>
<tr>
<th>DVH Parameter</th>
<th>Rectum Mean (Range)</th>
<th>Bladder Mean (Range)</th>
<th>Sigmoid Mean (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2cc</td>
<td>15% (5-22)</td>
<td>6% (3-12)</td>
<td>2% (1-14)</td>
</tr>
<tr>
<td>D1cc</td>
<td>15% (4-22)</td>
<td>6% (3-11)</td>
<td>2% (1-13)</td>
</tr>
<tr>
<td>D0.1cc</td>
<td>13% (3-22)</td>
<td>6% (1-11)</td>
<td>2% (1-12)</td>
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7. Conclusions

Successful ICBT delivery depends on selection of the best applicator, optimal applicator placement, and imaging for visualization and treatment planning, to minimize the risk of complications due to excess irradiation of adjacent normal structures. Elekta’s Fletcher CT/MR Shielded Applicator provides a novel and highly reproducible approach to optimize ICBT delivery to provide high-fidelity images while retaining the use of bladder and rectal shields.

Model-based dose calculation algorithms, such as Advanced Collapsed cone Engine (ACE), have the potential to accurately model the primary dose attenuation and full three-dimensional scatter around shields, which will increase the appeal of using a shielded applicator.

8. Summary

- The Fletcher CT/MR Shielded Applicator significantly reduces radiation dose to the rectum, bladder, and sigmoid.

- The most significant reductions are shown in the rectum.

- Reduction to OAR is largely influenced by the patient's anatomy and packing.

- TG43 based treatment planning underestimates the impact of the Fletcher CT/MR shielded applicator. The powerful combination of ACE and the applicator provides clinicians with more accurate dose predictions of OAR.
9. Definition of Terminology

<table>
<thead>
<tr>
<th>Abbreviation / definition</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACE</td>
<td>Advanced Collapsed Cone Engine</td>
</tr>
<tr>
<td>CCC</td>
<td>Collapsed Cone Convolution</td>
</tr>
<tr>
<td>CT</td>
<td>Computed Tomography</td>
</tr>
<tr>
<td>ICBT</td>
<td>IntraCavitary BrachyTherapy</td>
</tr>
<tr>
<td>MR</td>
<td>Magnetic Resonance</td>
</tr>
<tr>
<td>OAR</td>
<td>Organs-At-Risk</td>
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<tr>
<td>ROI</td>
<td>Region-Of-Interest</td>
</tr>
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<td>FSE</td>
<td>Fast Spin Echo</td>
</tr>
</tbody>
</table>

10. References


Committed to Brachytherapy

Elekta brachytherapy solutions are part of Elekta’s leading radiation therapy portfolio and encompass more than 35 years of Nucletron® innovations. These advanced products include Esteya® electronic brachytherapy, Flexitron® afterloading, Oncentra® Brachy treatment planning, the broadest range of applicators in the industry and Real-time Prostate solutions.

A human care company, Elekta pioneers significant innovations and clinical solutions harnessing both external and internal radiation therapy for treating cancer and brain disorders. Elekta provides intelligent and resource-efficient technologies that improve, prolong and save patient lives. We go beyond collaboration, seeking long-term relationships built on trust with a shared vision, and inspiring confidence among healthcare providers and their patients.

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