Design, Production and Evaluation of Personalized 3D Printed IC Brachytherapy Applicators

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B. BASARIC [1], L. MORGAN [1], C. ENGELBERTS [1], M. CROCKER [2], R. ORBOVIC [1], E. ORTON [1], J. ROBAR [2,3]

1 Adaptiiv Medical Technologies Inc., Halifax, NS, Canada
2 Dalhousie University, Halifax, NS, Canada
3 Nova Scotia Health Authority, Halifax, NS, Canada

INTRODUCTION

Intracavitary (IC) brachytherapy modality has been traditionally offering a vast number of commercially available **generic applicators**, i.e. **one-size-fits-all-patients**, thus there has been very little or no opportunity to customize shape, size and direction of source trajectory paths in respect to a specific patient anatomy [1].

Therefore, a **novel software** tool is introduced for designing **personalized IC and IC/IS brachytherapy applicators**, compatible with 3D printing technology and RT equipment.

AIM

1. To **design software** with the following features:
   - Importing of applicator contours from TPS via DICOM RT Structure Set file and displaying them over CT/MRI images.
   - Importing of optimized source-trajectory paths from TPS via DICOM RT Plan file and subtracting catheter/needle tunnels from the applicator employing user-defined diameters.
   - Rendering and exporting of an STL file of the modified applicator compatible with 3D printing technology.
   - Designing and exporting of DICOM RT structure set containing the modified applicator which can be imported back to TPS for commissioning and QA purposes.
2. To **3D print and evaluate the spatial fidelity** of the applicator in respect to the corresponding STL and RT structure and to **inspect HU homogeneity and mass density** of printed samples.

METHOD

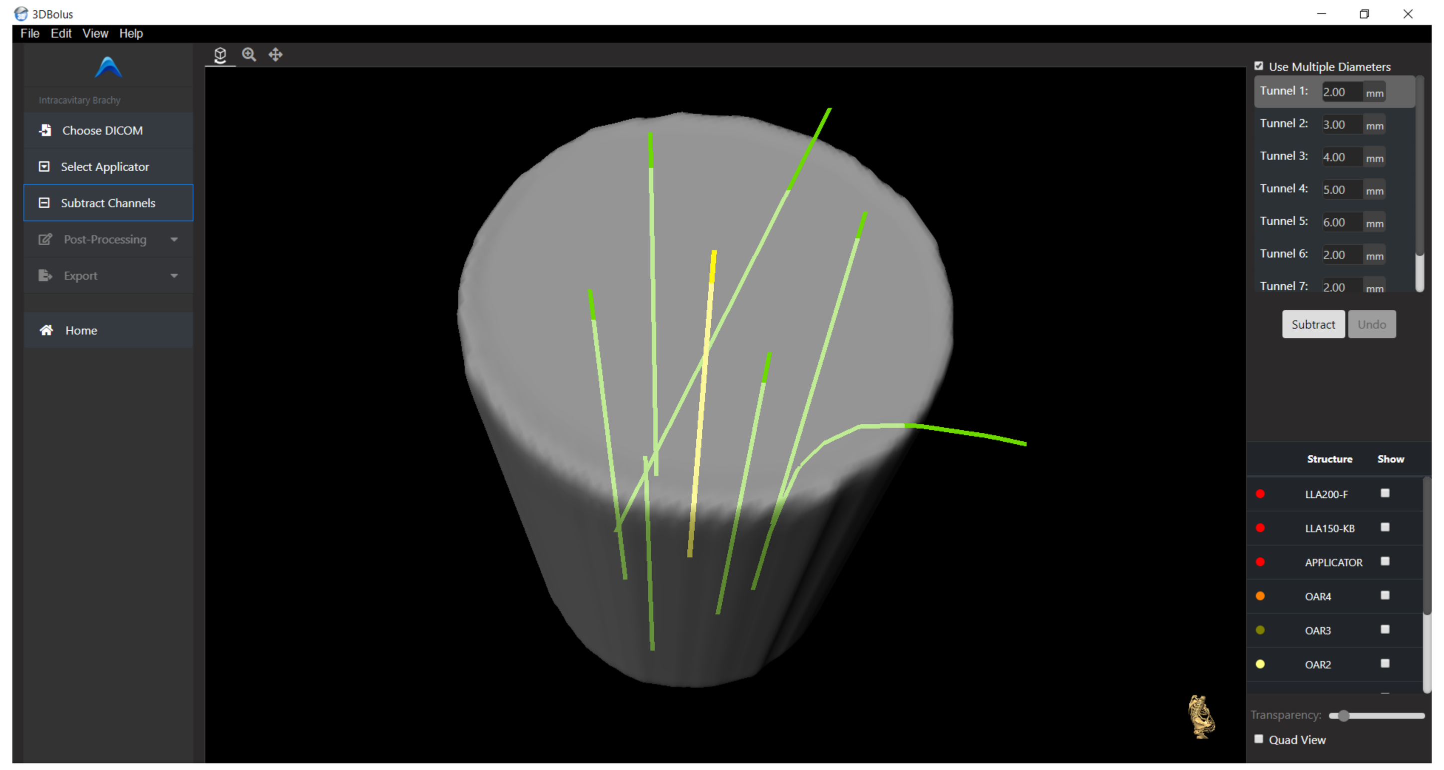
- **A software solution was designed** with the following features: DICOM import and DICOM/STL file export modules, source trajectory tunnel subtraction with user-defined diameters, 2D/3D image viewing tools, 2D ruler and attachment post-processing.
- A cylinder applicator was contoured in a brachytherapy TPS (SagiPlan 2.2, Eckert & Ziegler BEBIG) and 6 straight, 1 oblique and 1 curved source trajectories were re-created in the plan.
- **DICOM dataset** was exported from TPS and imported into **Adaptiiv Brachytherapy software v.3.1** (Adaptiiv Medical Technologies Inc. release due in Fall 2020, pending FDA 510k,) where the applicator was designed and rendered with user-defined tunnel diameters.
- The **software output** included the **RT Structure Set** file with the modified applicator and corresponding **STL** file which was used to 3D print the applicator on an SLA (Stereolithography) 3D printer (Form2, Formlabs) using 2 biocompatible resins: 'Surgical Guide' (Formlabs) and 'Dental SG' (NextDent) and 1 prototyping resin: 'Clear' (Formlabs).
- **Spatial fidelity** of the 3D printed applicators was quantified and compared to the corresponding RT structure and STL file.
- 3D printed samples were then CT-imaged, **HU homogeneity** was examined (automatically and manually), and **mass density** calculated.
- **Tolerance levels** were established for the spatial fidelity of the 3D printed applicator.

RESULTS

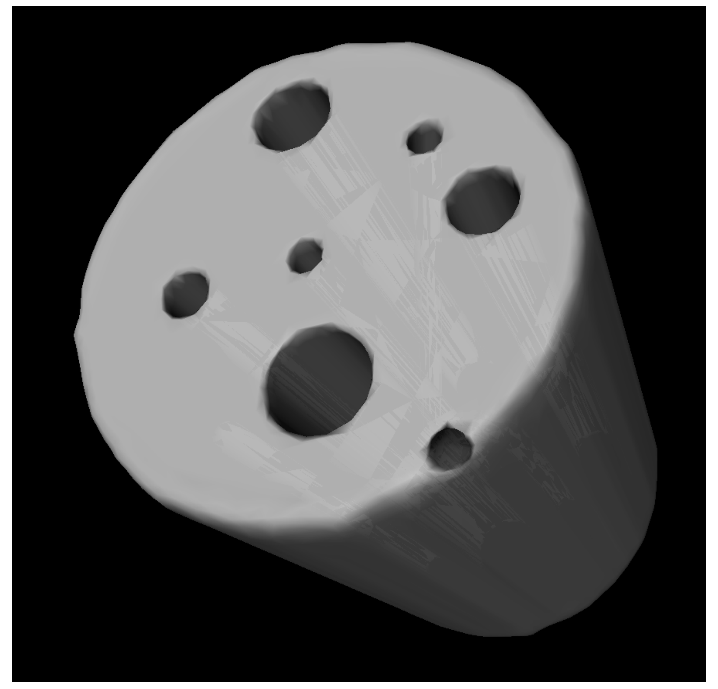
- The accuracy of applicator diameter, length, inter-tunnel distance and catheter-tunnel diameter was measured on 3D printed applicators, corresponding STL and RT structure resulting in ±0.2mm relative to the reference geometry set in TPS and Adaptiiv's Brachytherapy software.
- The angle of the oblique trajectory measured on the modified RT structured showed the accuracy of 0.1 degrees in respect to reference geometry set TPS.
- Comparing RT structure with corresponding STL of the modified applicator showed submillimeter accuracy (~0.01mm) using CloudCompare software.
- HU homogeneity test of cured, 3D printed Surgical Guide sample showed 88±28 HU (automatic analysis, Matlab) and 90±9 HU (manual point-analysis, Eclipse v13.6); Mass density for Surgical Guide resin was calculated to be 1.180±0.002 g/cc; For Dental SG resin, the HU analysis showed 96±15 HU (Matlab) and 98±8 HU (Eclipse). Mass density for Dental SG resin was calculated to be 1.210±0.002 g/cc.
- Tolerance levels regarding dimensions of the printed applicator were set to 1CT (MRI) pixel size (in plane) and 1CT (MRI) slice thickness (longitudinally).
- The workflow in Adaptiiv's Brachytherapy software took approximately 5 minutes and the printing of the applicator took 3 hours to accomplish.

Measurements	RT structure measured in TPS [mm]	RT structure measured in Adaptiiv software [mm]	STL measured in Meshmixer [mm]	3D printed applicator measured with calipers [mm]
Cylinder diameter lateral (x)	30.3	30.2	30.1	30.3
Cylinder diameter vertical (z)	30.3	30.2	30.1	30.2
Cylinder length longitudinal (y)	43.5	43.5	43.6	43.7
Inter-tunnel distance lateral	10	10	10.1	10.1
Inter-tunnel distance vertical	10	10.1	10.2	10
Tunnel diameter [set to 2mm]	N/A	1.9	1.9	1.8
Tunnel diameter [set to 3mm]	N/A	2.9	2.9	2.8

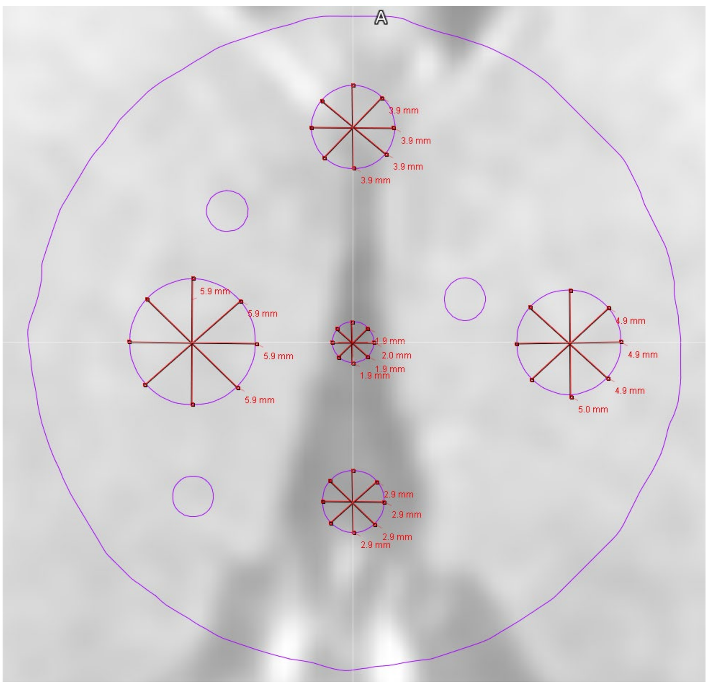
Spatial fidelity measurements of the modified applicator ('Surgical Guide' sample)



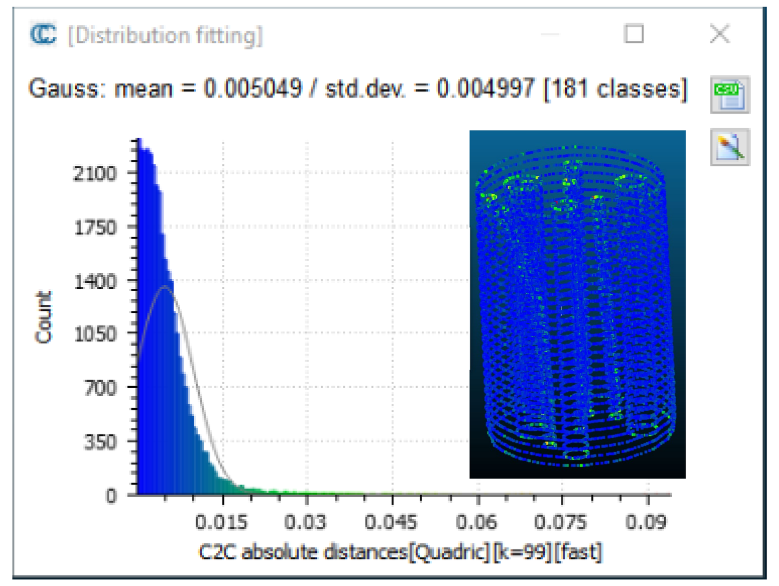
Adaptiiv's Brachytherapy software user interface



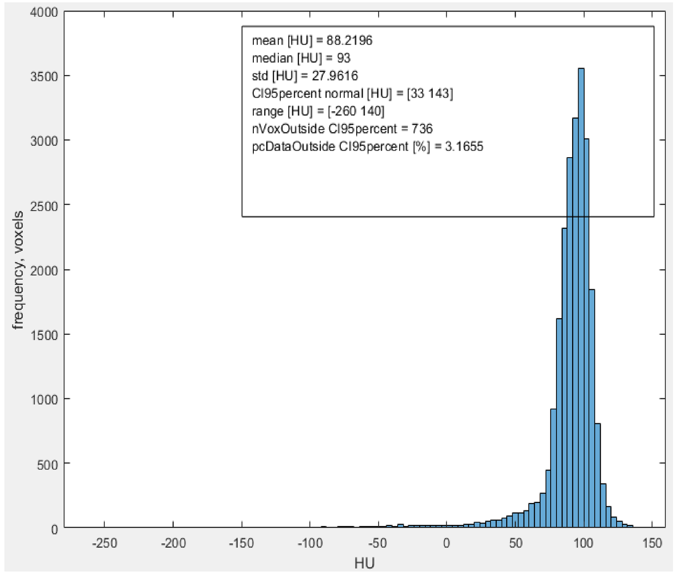
STL of the modified applicator 3D view



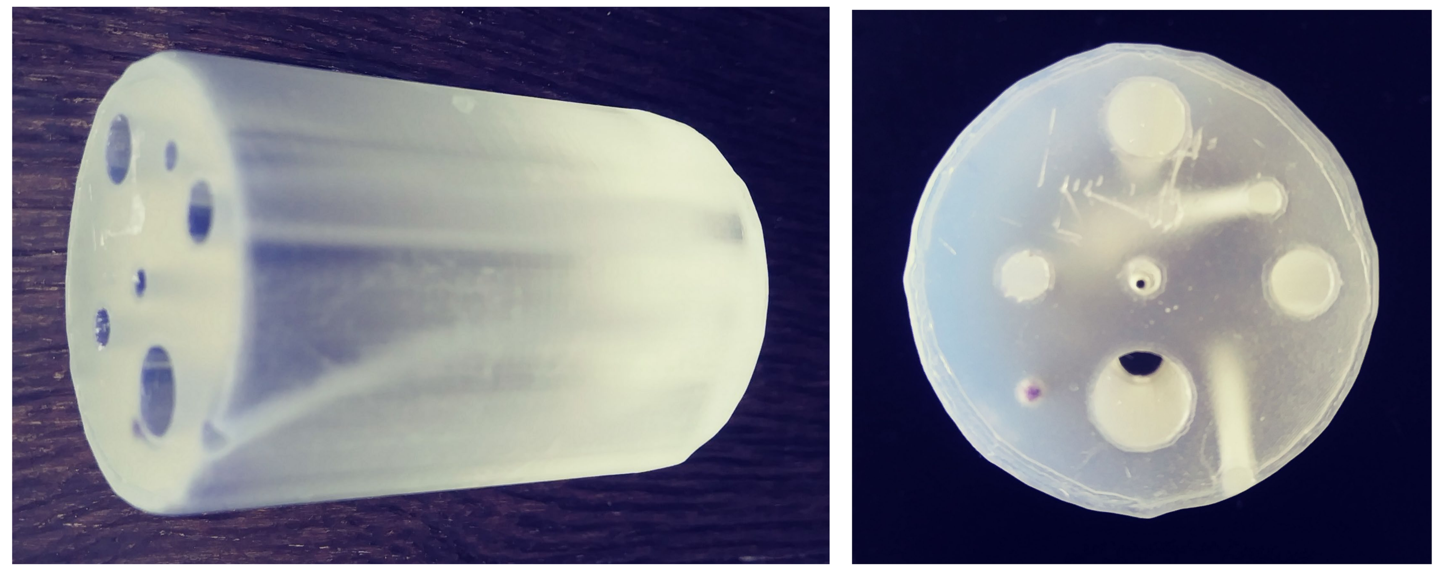
RT structure of the modified applicator axial 2D view



CloudCompare measurements between RT structure and STL of the modified applicator



Automatic HU analysis ('Surgical Guide' sample)



3D printed applicator - prototype sample in 'Clear' resin (Formlabs)

CONCLUSIONS

- Adaptiiv's Brachytherapy software was designed to be compatible with DICOM and STL file formats, effectively bridging the worlds of radiation therapy and 3D printing technology.
- Design and production of the applicator were accomplished in a short amount of time without the need for complex CAD software, specialized 3D modelling or other mechanical engineering skills.
- Implemented software features including DICOM/STL import and export modules, user-defined tunnel subtraction, 2D/3D viewing tools, 2D ruler and attachment post-processing provide tools necessary for clinical commissioning of Adaptiiv's Brachytherapy software in RT.
- 3D printed IC applicators showed a submillimeter level of spatial accuracy needed for clinical implementation.
- Radiological uniformity of 2 biocompatible applicator materials was demonstrated, with mass densities being close to water equivalent, implying the use of TG-43 protocol. Further dosimetric investigation of 3D printed materials needs to be performed.
- Clinical studies need to be conducted aiming at specific modifications of IC applicators in respect to shape/size/source trajectory orientations, assessing the impact on applicator fitting, target volume, dose conformity and sparing of OARs.

ACKNOWLEDGEMENTS

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CONTACT INFORMATION

Borko Basaric, MSc, MPS
Medical Physics Specialist / Product Owner - Brachytherapy Solutions
Borko.Basaric@adaptiiv.com
https://www.adaptiiv.com/