Personalized brachytherapy with integration of 3D printing technologies

James Robar, PhD, FCCPM
Professor of Radiation Oncology, Dalhousie University
Chief of Medical Physics, Nova Scotia Health
Disclosure

I am a co-founder of Adaptiiv Medical Technologies
Overview

• Why incorporate 3D printing into brachytherapy?
• Gynecological brachytherapy applications
  • Extending the flexibility of standard applicators
  • Fully customized applicators
• Surface brachytherapy applications
• Application to permanent seed implants
• Biocompatibility and sterilization
Why incorporate 3D printing into brachy?

1. **Dosimetric motivations**
   - Specify strategic catheter trajectories
   - Include interstitial needle paths without limitations
   - Combine intracavitary and interstitial applicators
   - Incorporation of in-printed, patient-specific shielding

2. **Patient experience and ease of use**
   - Enhanced fit for patient
   - Improved reproducibility

3. **Increase efficiency by digitizing manual processes**
   - Eliminate hand-fabricated moulds
   - Reduce manual steps (e.g., attachment of Freiburg flap)
3D printing in gynecological brachytherapy
Gyne brachytherapy
New degrees of freedom for standard applicators

Example: locally advanced cervix cancer with extension to parametria

- Based on Varian 26 mm tandem/ring applicator
- Ring channel removed, replaced by 8 equispaced needle guides
- Additional 5 needle guides through vaginal template
- Needle angles and extensions based on MRI treatment planning
- Multijet printing using Visijet M3 Crystal (USP Class VI)

Lindegaard et al, Radiotherapy and Oncology, 2016
Gyne brachytherapy
New degrees of freedom for standard applicators

- **Adaptiiv 3DBrachy** for IC/IS split-ring design
- Imports needle paths from TPS, allows arbitrary angles up to 45 degrees
- Allows for variation in ring radius
- Incorporates needle guide tube notches
- 3D printable with SLA, Biomed Clear or MED-AMB
- Needle tunnel diameters accurate to 0.1 mm (Basaric, 2021)
- Compatible with EZ/BEBIG ring/tandem hardware

Adaptiiv 3DBrachy design software
Basaric et al, World Congress of Brachytherapy, 2021

FDA 510(k) clearance pending
Gyne brachytherapy
New degrees of freedom for standard applicators

• Kamio et al (2021) implemented toward EMBRACE II study requirements
• Printed with Surgical Guide and Biomed Clear SLA resins
• Evaluated mechanical viability pre- and post-sterilization
• Found acceptable tolerances ~0.1 mm and functionality
• Dubbed Montreal split-ring

Adaptiiv Montreal split-ring applicator
Kamio et al, Canadian Organization of Medical Physicists Annual meeting, 2020
Kamio et al, World Congress of Brachytherapy, 2021
Gyne brachytherapy
Fully customized applicators

- **Example:** patient-specific applicators for stage IIIA/B cervical cancer with paravaginal and parametrial extension (Laan *et al*, 2019)
- MRI with aqueous gel for distension and visibility
- Pre-planning based on MRI
- Single applicator can contain IC trajectories an IS needle guides

Laan *et al*, 3D Printing in Medicine, 2019
Gyne brachytherapy
Fully customized applicators

- The **Halifax Applicator**
- Designed in Adaptiiv 3DBrachy
- Combination of IC and IS trajectories in single applicator
- Integrates into BEBIG tandem
- Printable using SLA or MJF biocompatible materials

FDA 510(k) clearance pending
Gyne brachytherapy
Fully customized applicators

01 Scan a patient with a ‘dummy’ applicator
02 Pre-plan
03 Design a 3D model of Halifax Vault Applicator
04 Print and QA the applicator
05 Scan the patient with the 3D printed applicator
06 Plan. QA. Treat.
Gyne brachytherapy
Incorporation of anatomy-specific shielding

Fig. 2. The design of the patient-specific applicator, conforming the WPLA shielding to the size and location of the target volume. OAR: organ at risk, PMMA: polymethyl methacrylate, and WPLA: tungsten-polylactic acid composite.
Gyne brachytherapy
Incorporation of anatomy-specific shielding

Fig. 5. (a) Mass attenuation coefficients for different applicator materials as a function of photon energy and corresponding (b) dose profiles in water for generic applicators.
3D printing in surface brachytherapy
Surface brachytherapy

Patient-specific applicators

- **3D printed surface applicators** replace wax moulds or Freiburg flap
- Gives user control over catheter spacing, distance to surface

- Software includes physical constraints, e.g., minimum radius of curvature
Surface brachytherapy
Patient-specific applicators

**Example:**
Chytyk-Praznik *et al* (AAPM 2020)

- Treatment of bilateral lesions on shins
- Each applicator included 13 catheter tunnels to cover multiple PTVs
- Applicators designed in 3DBrachy and FDM-printed using PLA
- Observed excellent fit, efficient placement and treatment delivery
- Allows customization of trajectories compared to Freiburg flap

Chytyk-Praznik *et al*, AAPM/COMP Annual Meeting, 2020
Other applications of 3D printing in brachytherapy
Templates for permanent seed implant

- **3D printed templates** based on imaging
- Array of needle guides control both needle orientation and depth
- Reports on use for treatment of ameloblastoma, rectal, pancreatic, liver, thoracic, brain tumours with I-125
- Provide a patient-specific alternative to freehand methods

3D printed brachy applicators
Biocompatibility and sterilization

- Biocompatibility requirement depends on the substrate (e.g., intact skin / mucosa / breached skin)
- Depends on the duration (e.g. < 24h vs > 24h)
- United States Pharmacopeia assesses adverse effects in animal studies, provides categorization of **Class I to VI**
  - For brachytherapy application with < 24h duration
    - Class I for intact skin
    - Class III for breached skin
    - Class V for mucosal surfaces
  - However, now there are **many** Class VI printable materials (conservative option)
    - **SLA** Accura ClearVue (3D Systems), BioMed Clear (Formlabs)
    - **Multijet Fusion** PA12 and TPU (HP)
- To be widely useful, should be **autoclave/steam sterilizable**, e.g., 132 deg / 4 min
  - Many SLA and MJF-printed materials satisfy this requirement
  - Many FDM-printed materials do not
Summary

• In gynecological brachytherapy, 3D printing has introduced
  • Patient-specific extension of standard applicators, e.g., tandem/ring to include custom needle guides
  • Fully customized combined IC/IS applicators

• In surface brachytherapy
  • Custom patient applicators allow control over source trajectory, spacing, distance from the skin
  • Can be fabricated to conform to complex surfaces

• Software solutions exist that interface with the TPS and do not require CAD skills

• In permanent-seed implants, 3D printed templates conform to the skin and eliminate freehand methods

• MJF and SLA have been the 3D printing methods of choice

• There is a range of USP Class VI and sterilizable materials available