# Personalized brachytherapy

## with integration of 3D printing technologies

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AAPM 2021 SAM Session
Brachytherapy technology horizon

# 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

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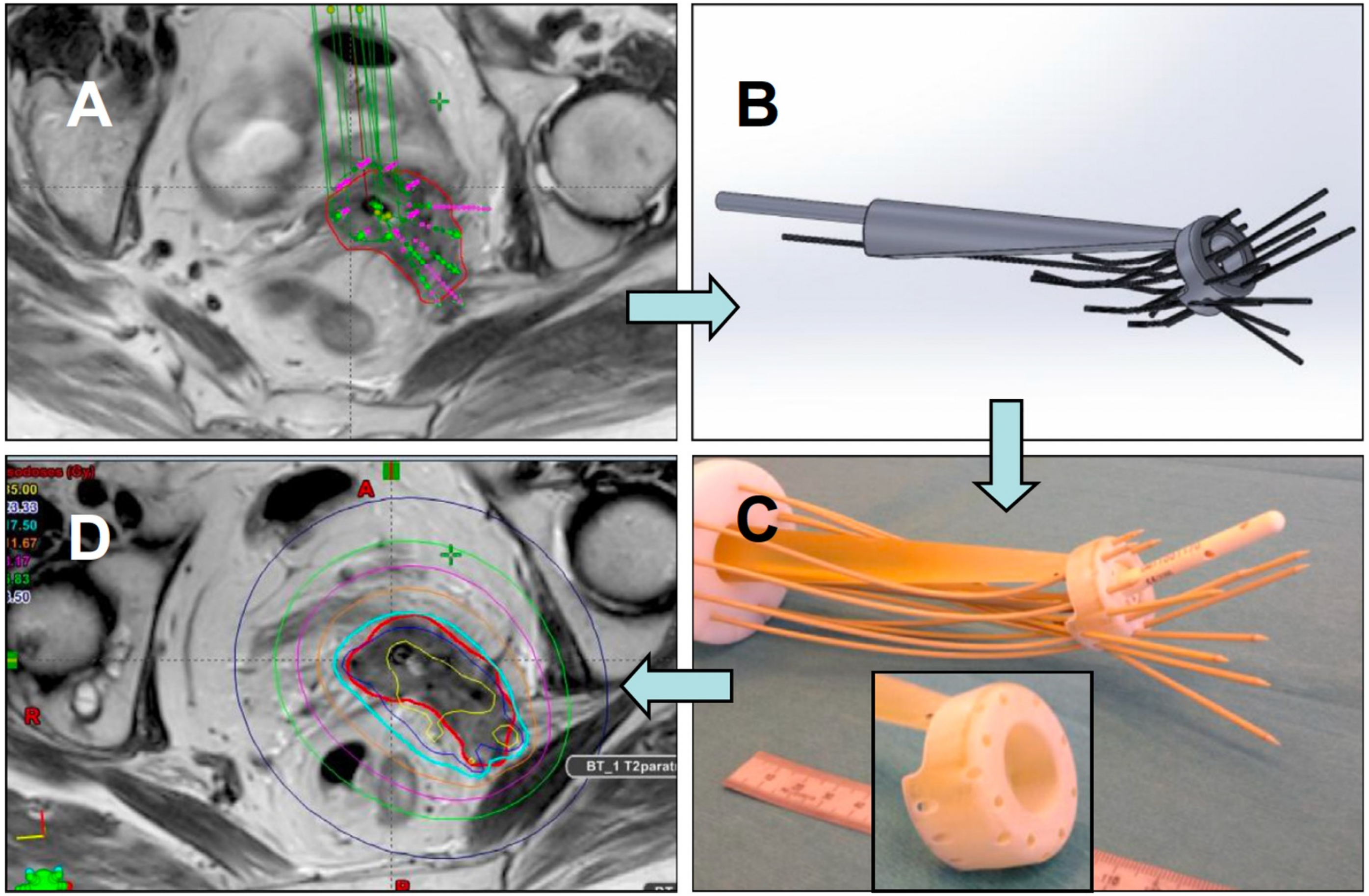
# Gyne brachytherapy
## New degrees of freedom for standard applicators

**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)

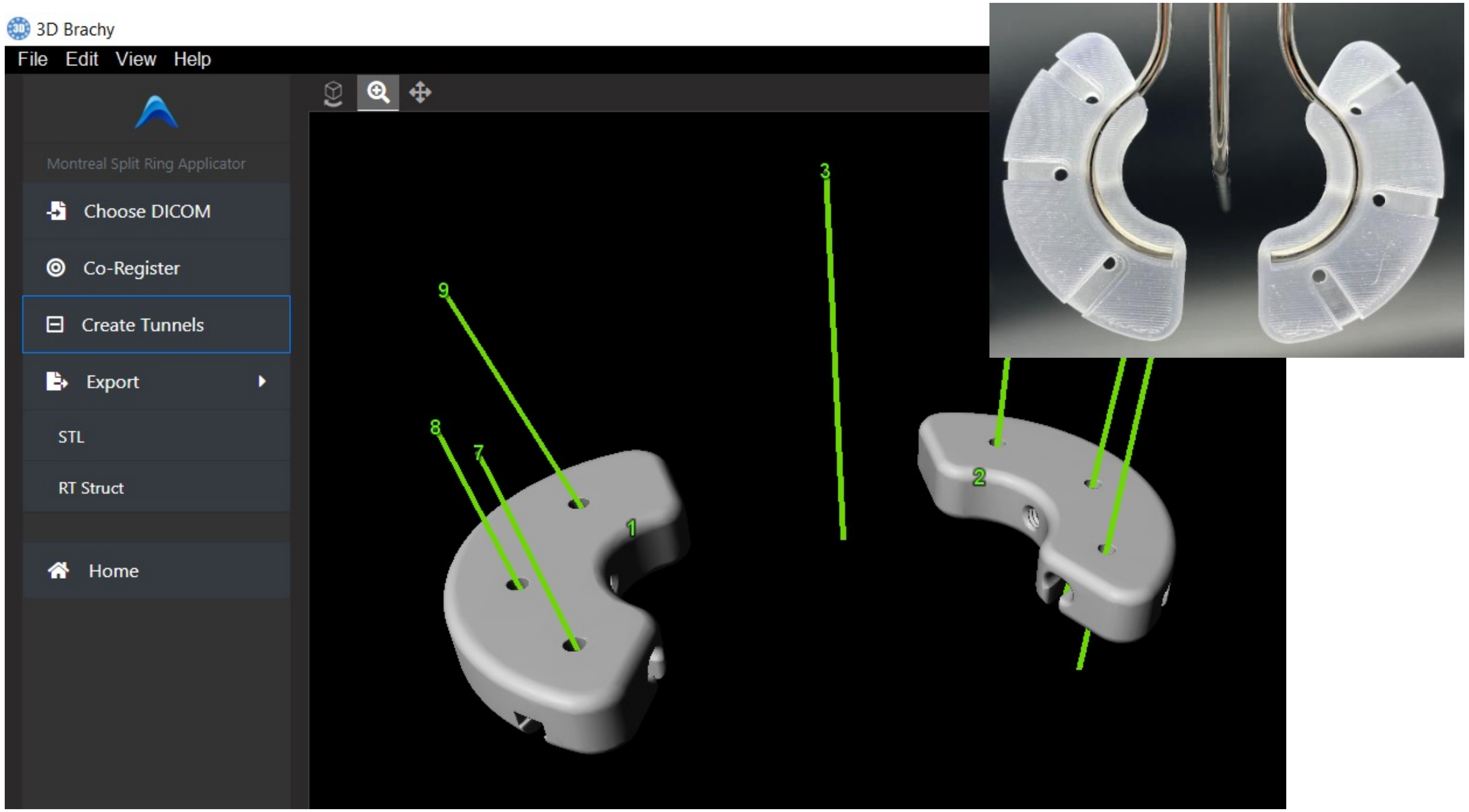



Lindegaard *et al*, Radiotherapy and Oncology, 2016

# 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

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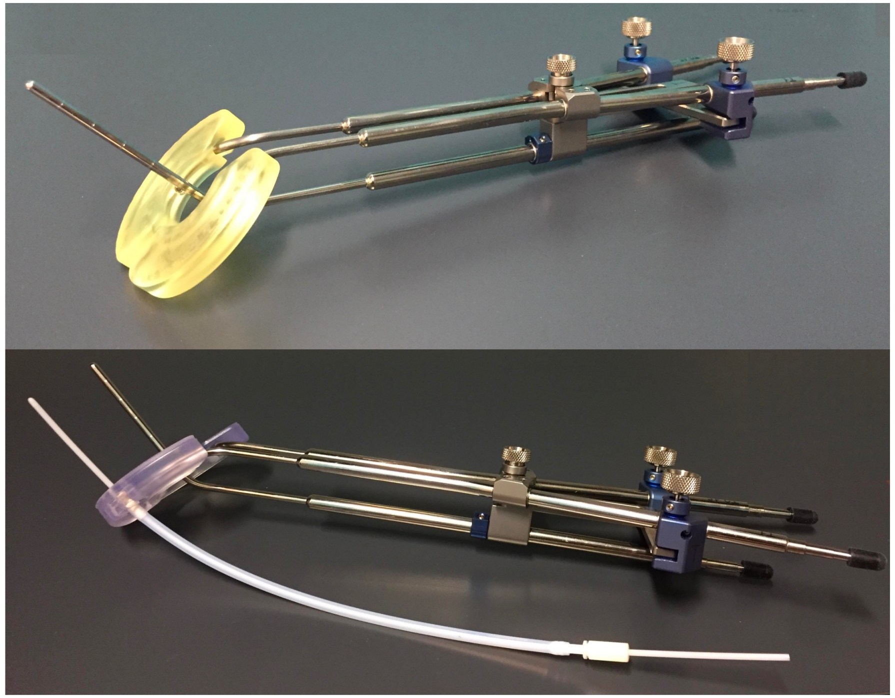
FDA 510(k) clearance pending

# 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**



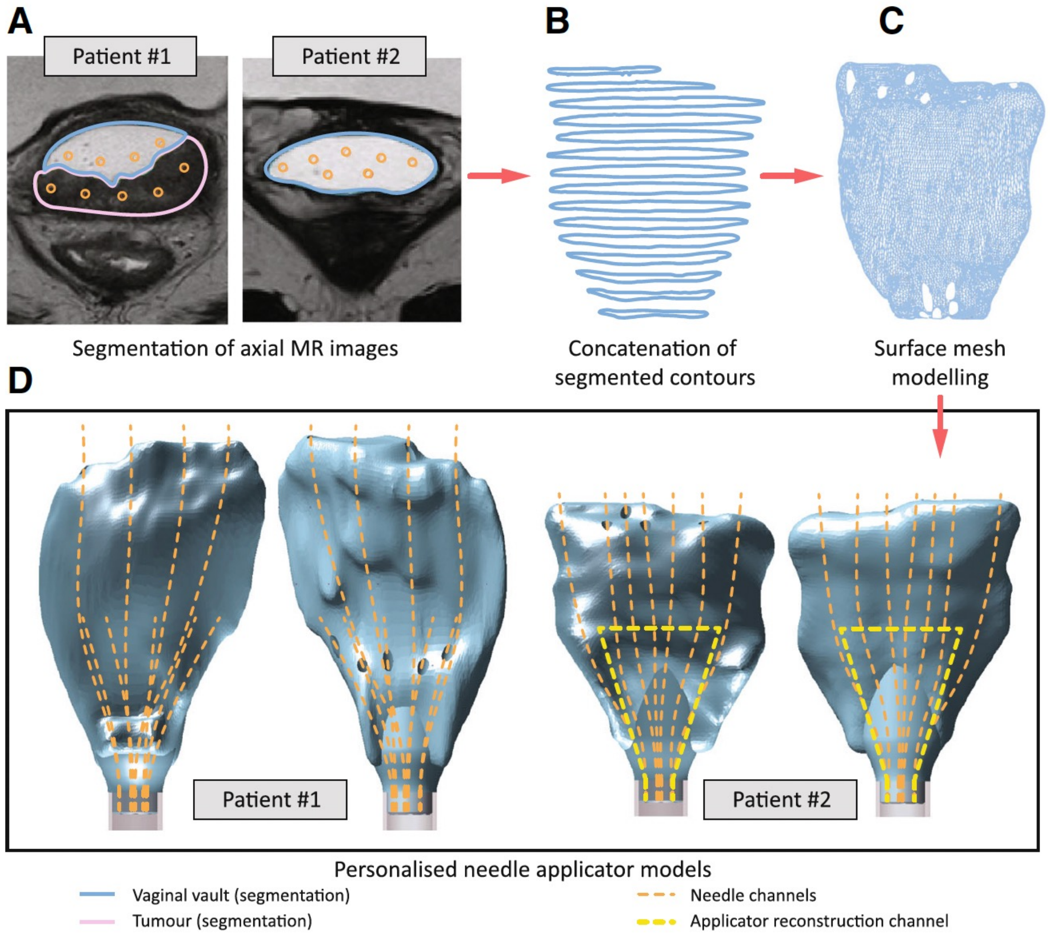

Adaptiiv Montreal split-ring applicator

Kamio et al, Canadian Organization of Medical Physicists Annual meeting, 2020

Kamio et al, World Congress of Brachytherapy, 2021

# Gyne brachytherapy
## Fully customized applicators

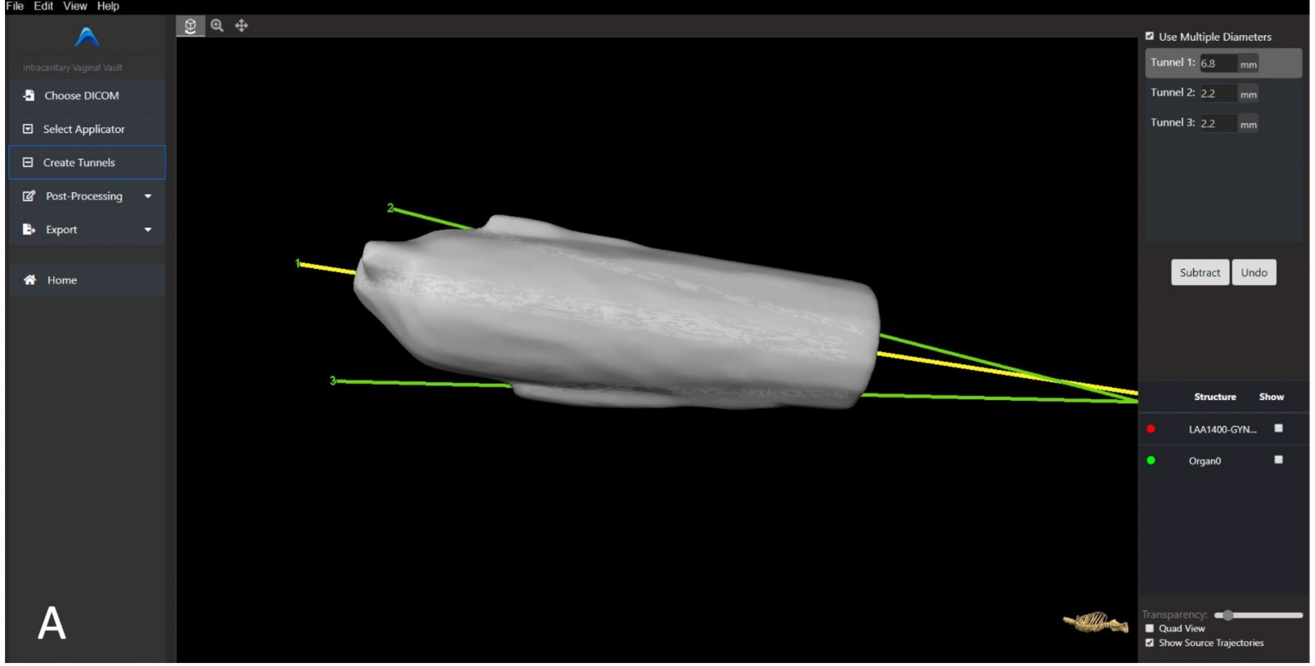
- **Example:** patient-specific applicators for stage IIIA/B cervical cancer with paravaginal and parametrial extension (Laan *et al,* 2019)
- MRI with aqueous gel for distension and visibility
- Pre-planning based on MRI
- Single applicator can contain IC trajectories an IS needle guides

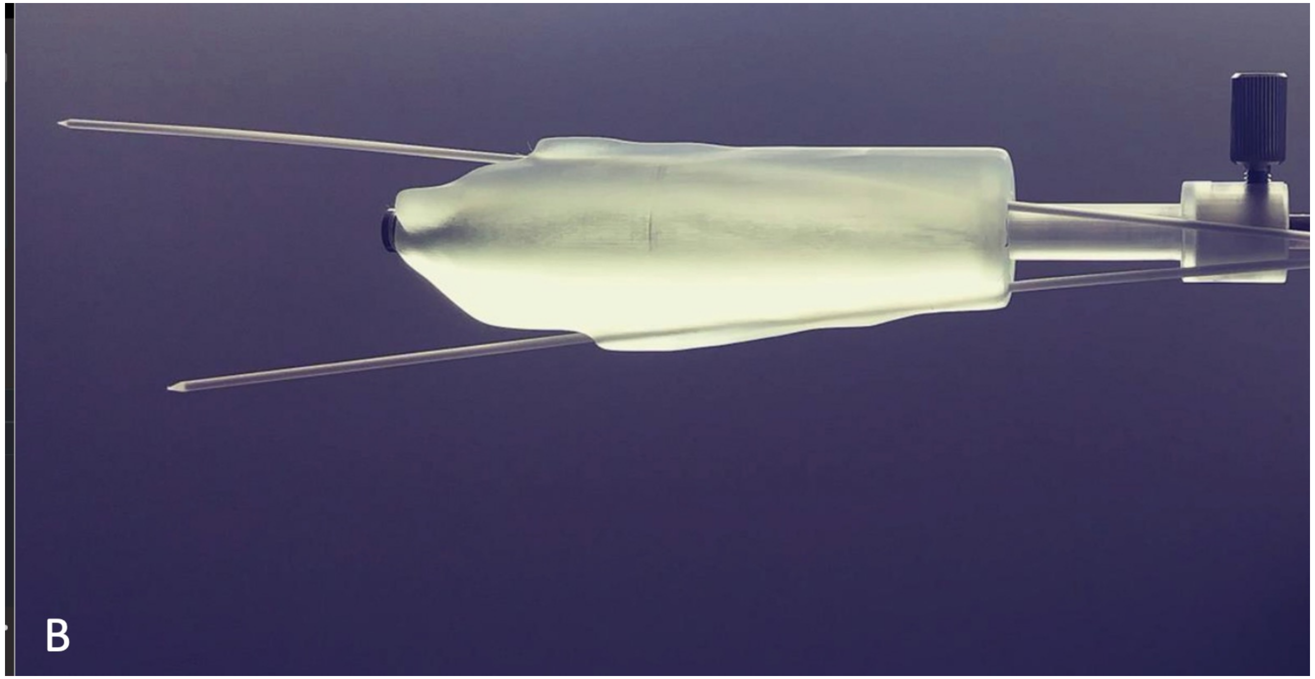



Laan *et al*, 3D Printing in Medicine, 2019

# 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

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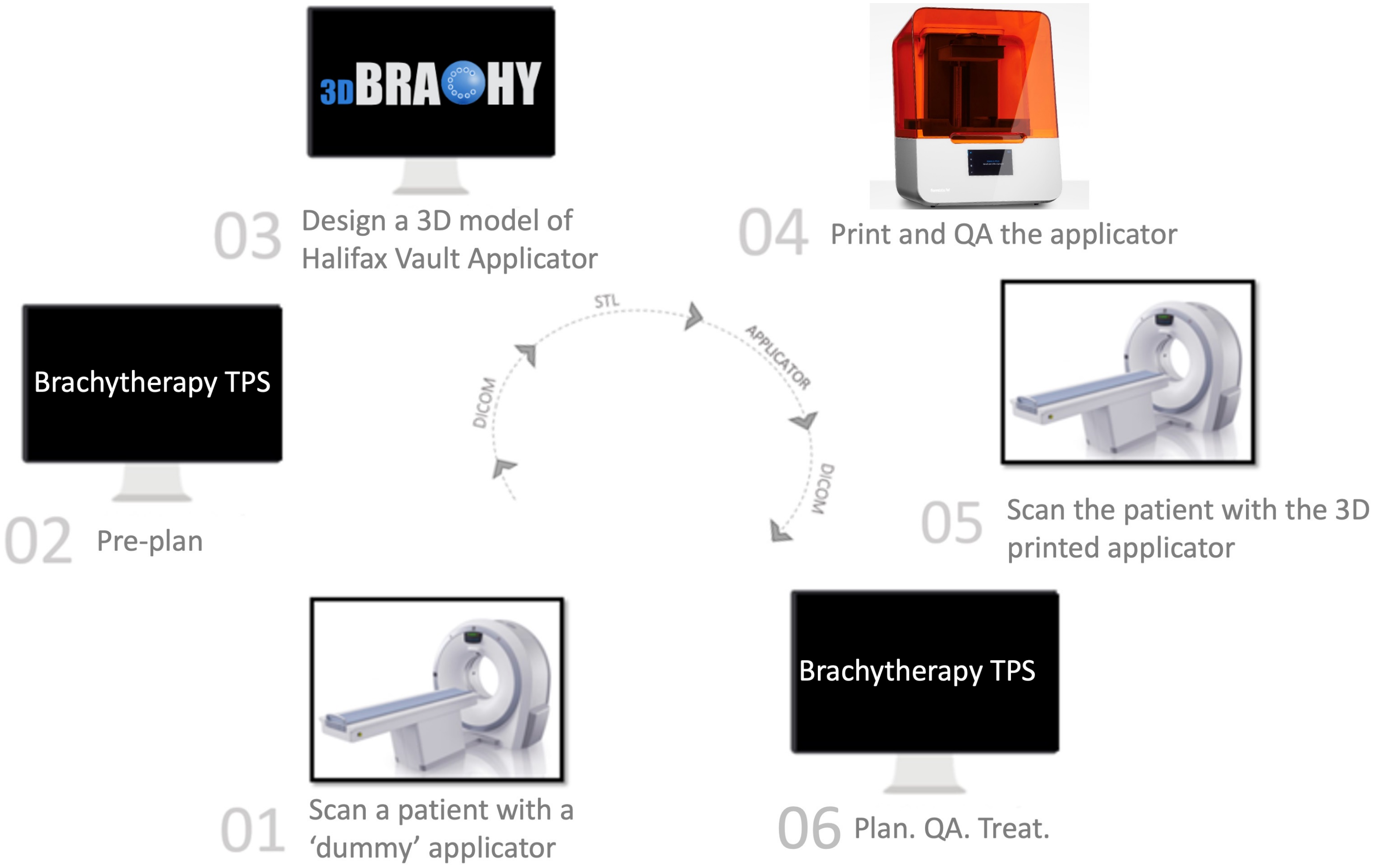
# Gyne brachytherapy

## Fully customized applicators

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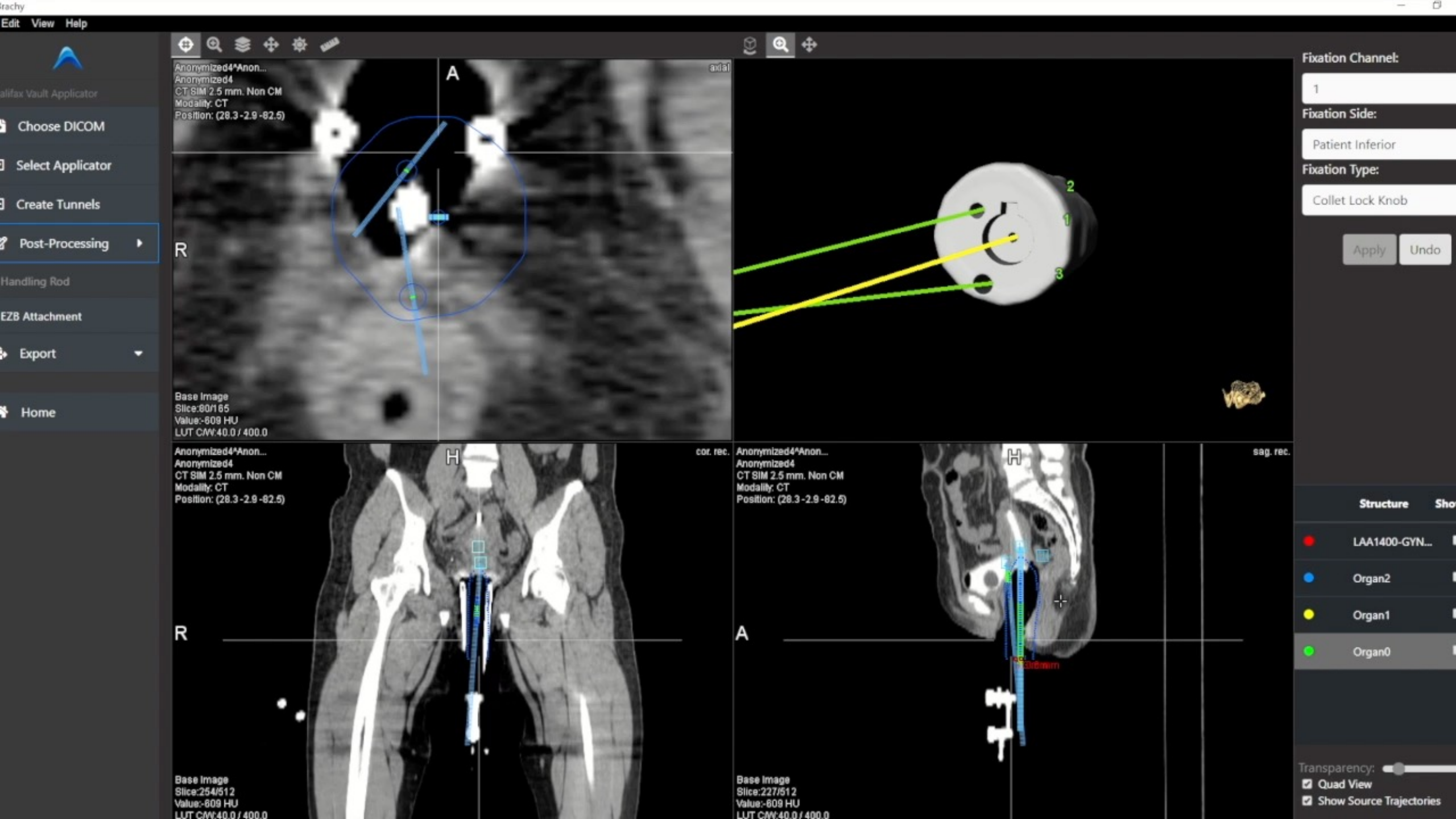

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# Gyne brachytherapy
## Incorporation of anatomy-specific shielding

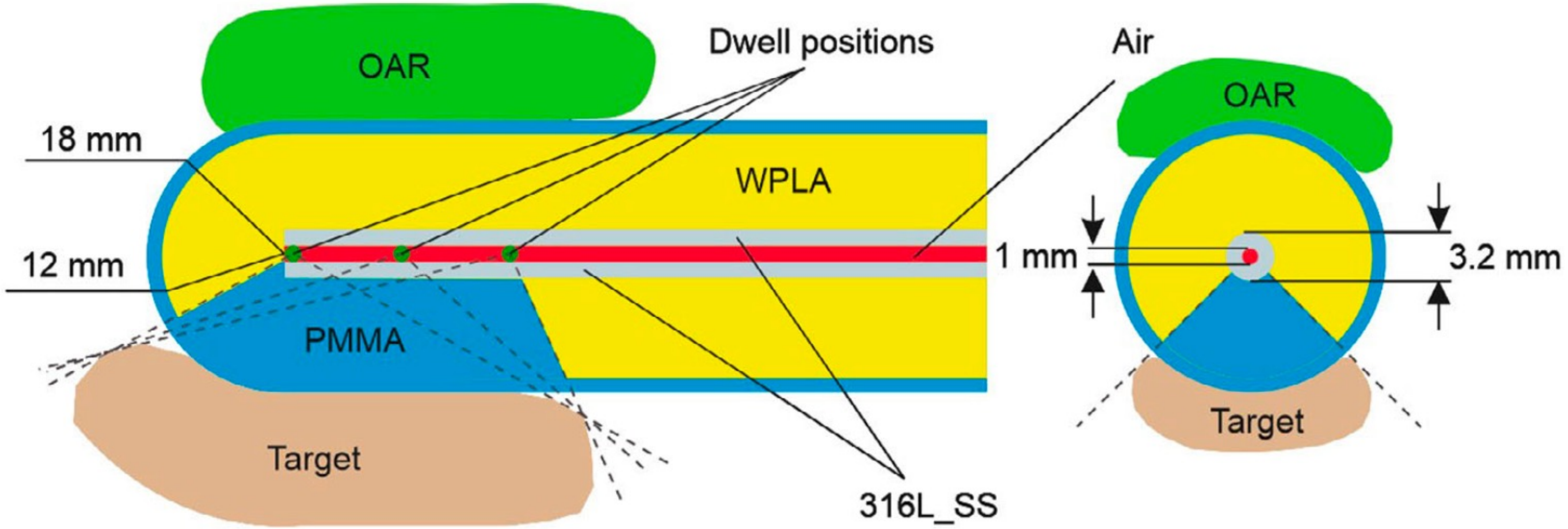


FIG. 2. The design of the patient-specific applicator, conforming the WPLA shielding to the size and location of the target volume. OAR: organ at risk, PMMA: polymethyl methacrylate, and WPLA: tungsten-polylactic acid composite.



Semeniuk *et al*, Medical Physics, 2021

# Gyne brachytherapy

## Incorporation of anatomy-specific shielding

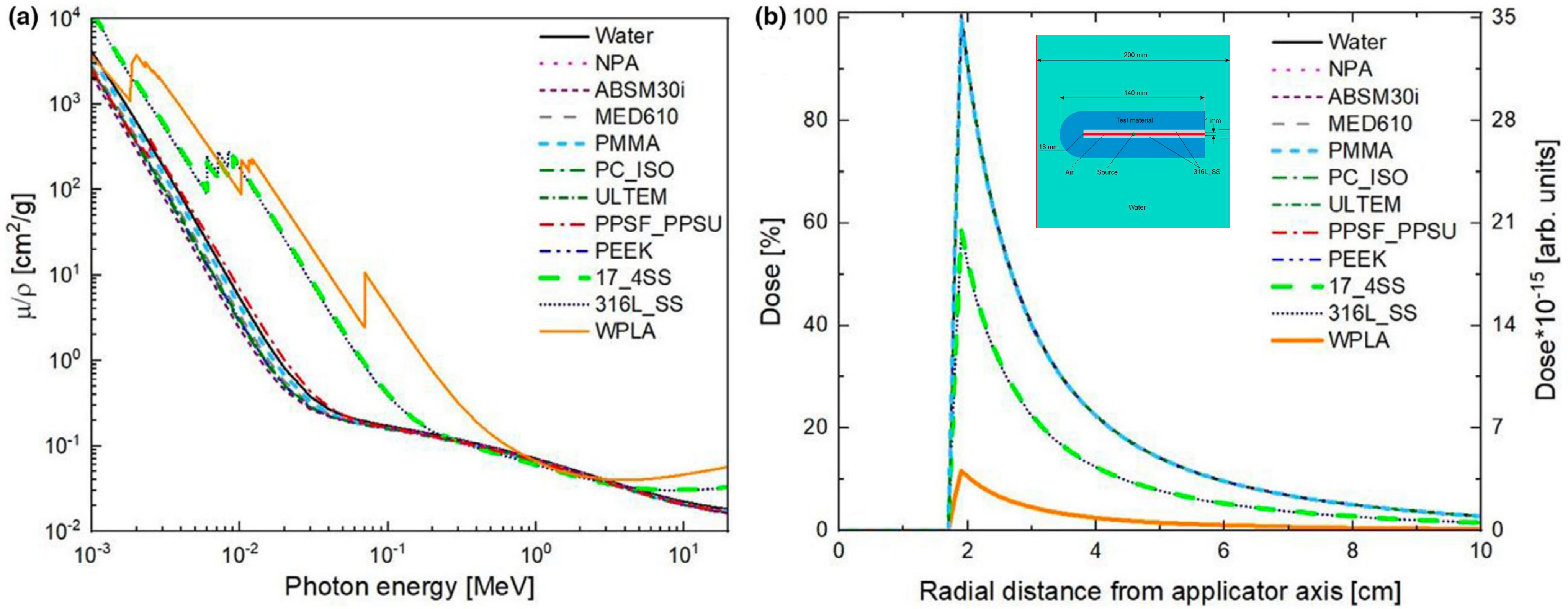


FIG. 5. (a) Mass attenuation coefficients for different applicator materials as a function of photon energy and corresponding (b) dose profiles in water for generic applicators.

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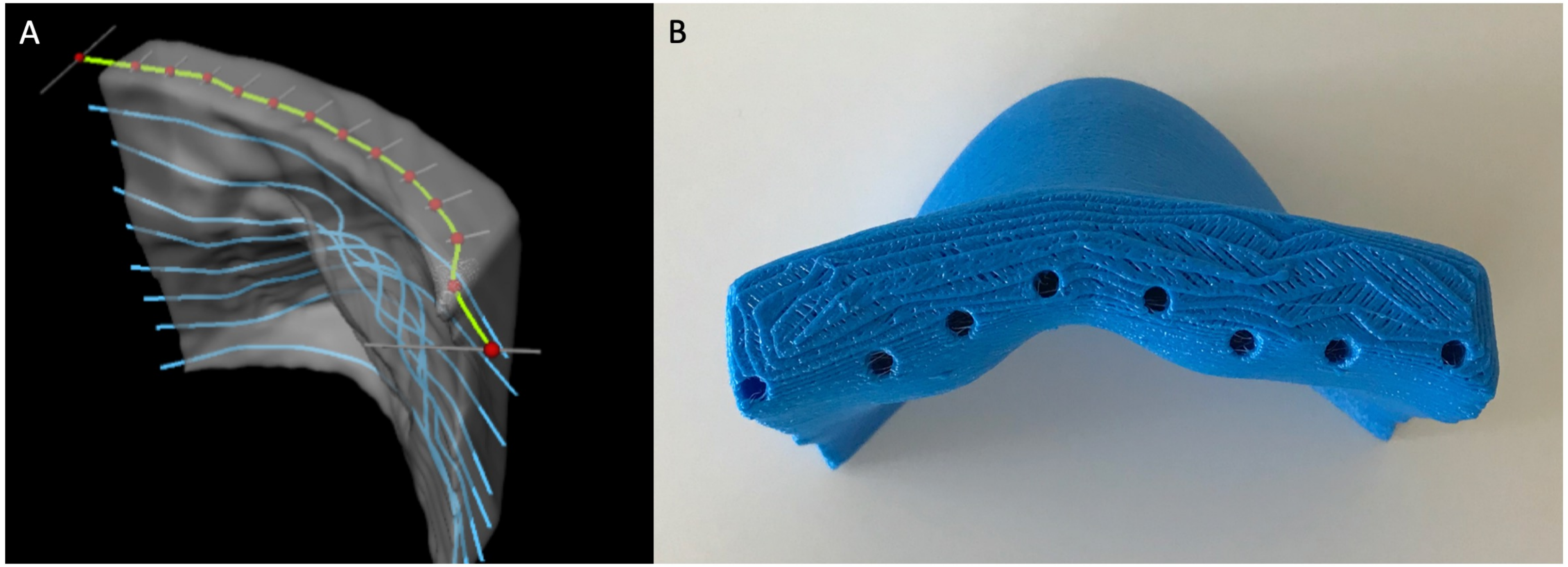
Semeniuk *et al*, Medical Physics, 2021

# 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

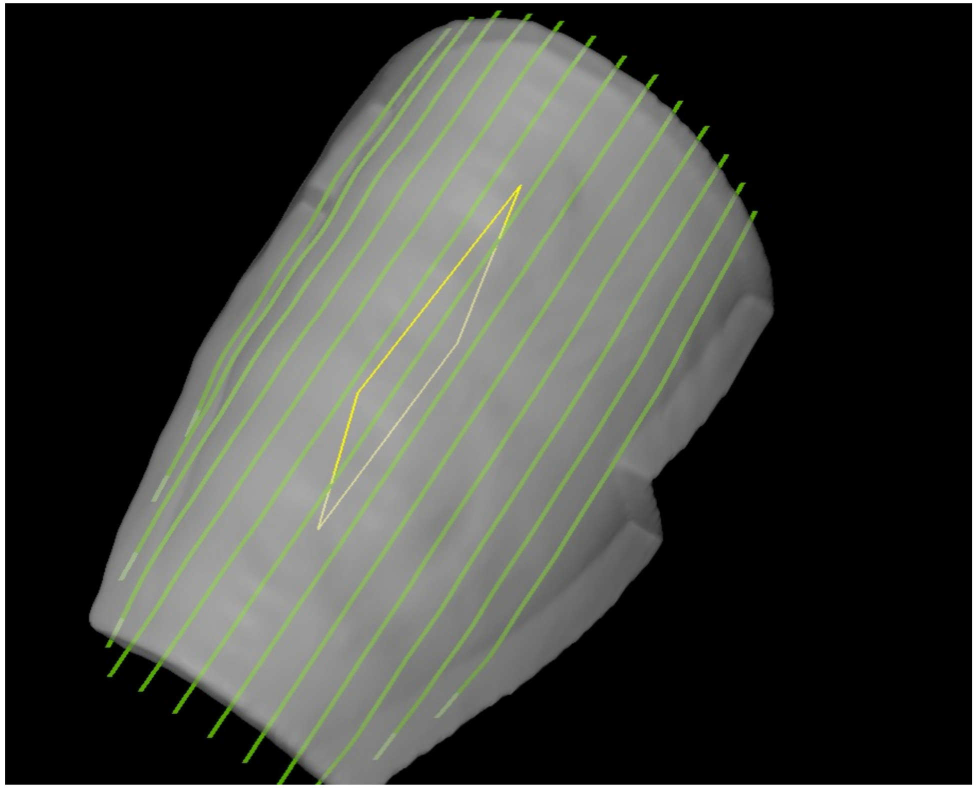
- Software includes physical constraints, e.g., minimum radius of curvature

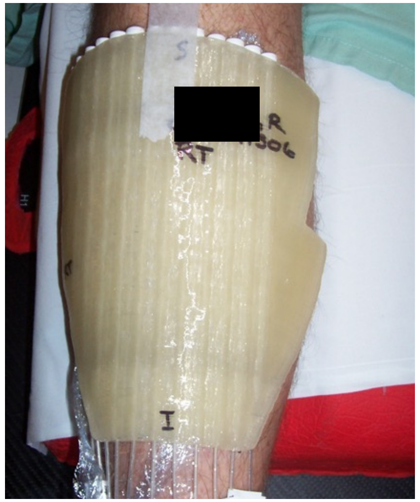


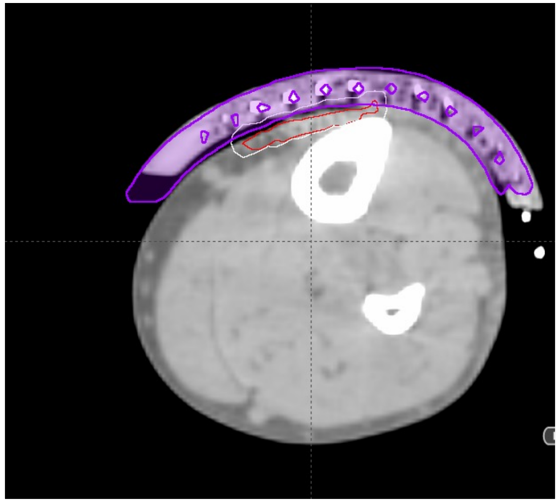
# Surface brachytherapy
## Patient-specific applicators

**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





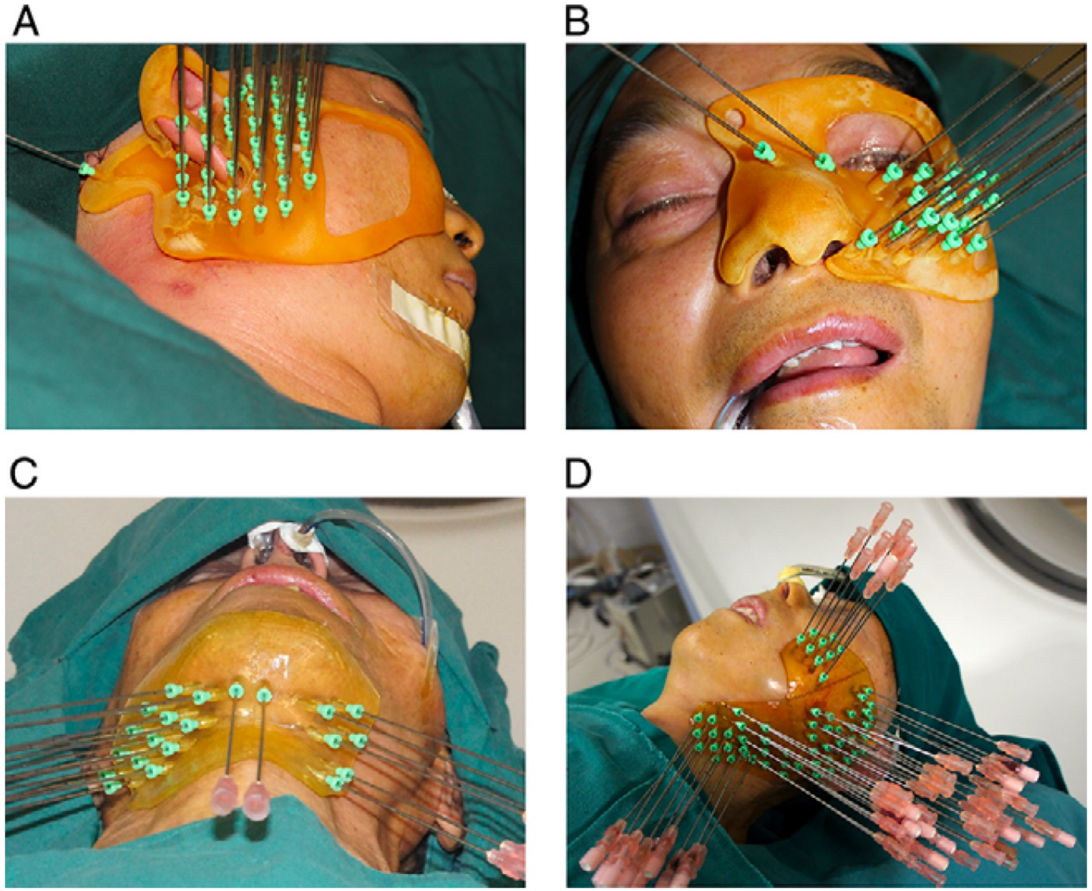


Chytyk-Praznik *et al*, AAPM/COMP Annual Meeting, 2020

# 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




Huang *et al*, J. Radiat Res, 2016.

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# 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