Intensity Modulated and Anisotropic Brachytherapy Sources (IMABS)

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Director | Medical Physics Graduate Program | CAMPEP-Accredited
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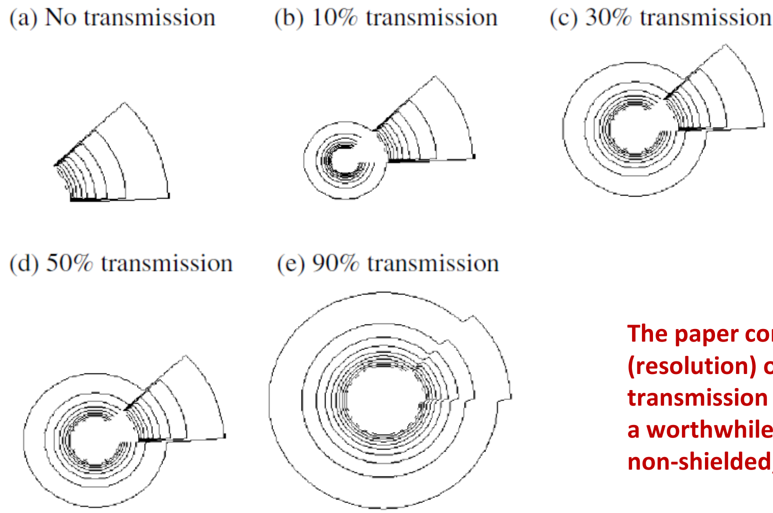
Disclosure

- Related to IMABS:
  - Current research funding from Varian (Siemens Healthineers)
  - Past research funding from Elekta
- Research funding from ViewRay, Inc.

What is IMBT?

- Intensity Modulated Brachytherapy?
- Ebert, 2002



The paper concludes that a collimation angle (resolution) of 22.5° - 45° and shielded-side transmission of <10% (leakage) are needed to see a worthwhile benefit of IMBT over conventional, non-shielded, brachytherapy implants

Figure 1. Resulting dose distribution from a single orientation of a linear source where the high-intensity region covers an angle of $\pi/4$ for differing levels of transmission through the low-intensity region of the source. The effect is nonlinear due to the dose fall-off relationship with distance from the source. The source is in the centre of each isodose distribution. Scale and isodose values are arbitrary. View is of the xy plane (i.e. along the source axis).

Ebert, Phys Med Biol 2002;47:2495-2509.

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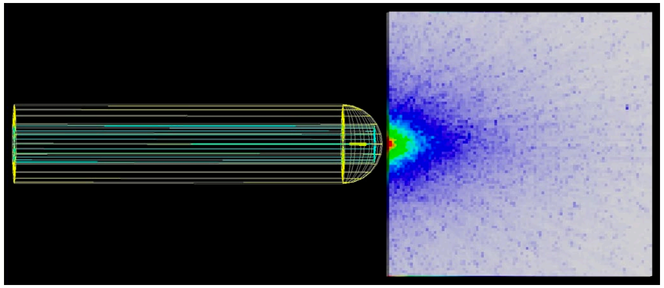
What is IMABS?

- Intensity Modulated and Anisotropic Brachytherapy Sources (IMABS)
- Task Group 337 – Formed 2019
- What do we mean by IMABS?

"IMABS provides at least one additional degree of freedom in the dose delivery process in order to achieve higher degree of dose conformality, e.g., a directionality in the dose profile (***anisotropic***) as opposed to the standard ***isotropic*** profile, achieved through incorporation of high-density shielding materials"

Cunha, *et al*., Semin Radiat Oncol 2019;30:94-106.



Moeen Meftahi, PhD Thesis (2021, in progress).

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What is IMABS?

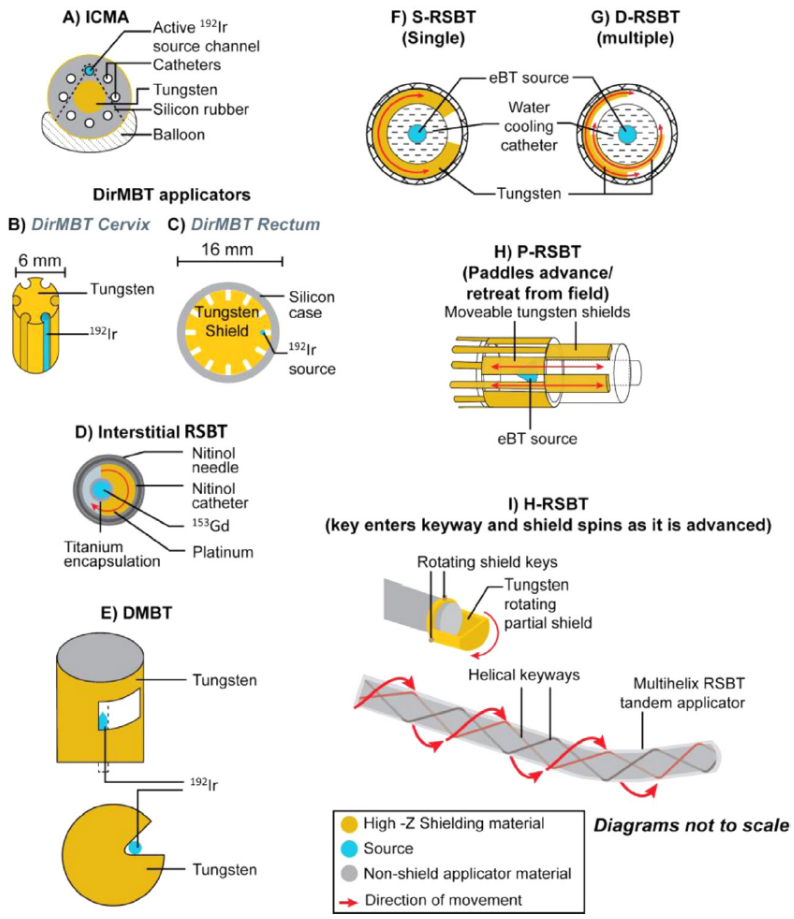

Figure 3 Examples of self-shielded applicators: (A) intracavitary mold applicator (ICMA), (B) direction-modulated brachytherapy (DirMBT) applicators for cervical cancer and (C) rectal cancer, (D) interstitial rotating shield brachytherapy (RSBT) for prostate cancer, (E) dynamic modulated brachytherapy (DMBT), (F) single-shield RSBT, (G) dynamic RSBT with multiple shields, (H) paddle-based RSBT, and (I) helical rotating shield brachytherapy for cervical cancer. Adapted with permission from Callaghan CM et al.[138]

Cunha, *et al.*, Semin Radiat Oncol 2019;30:94-106.

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A Well-Suited Problem? Cervix

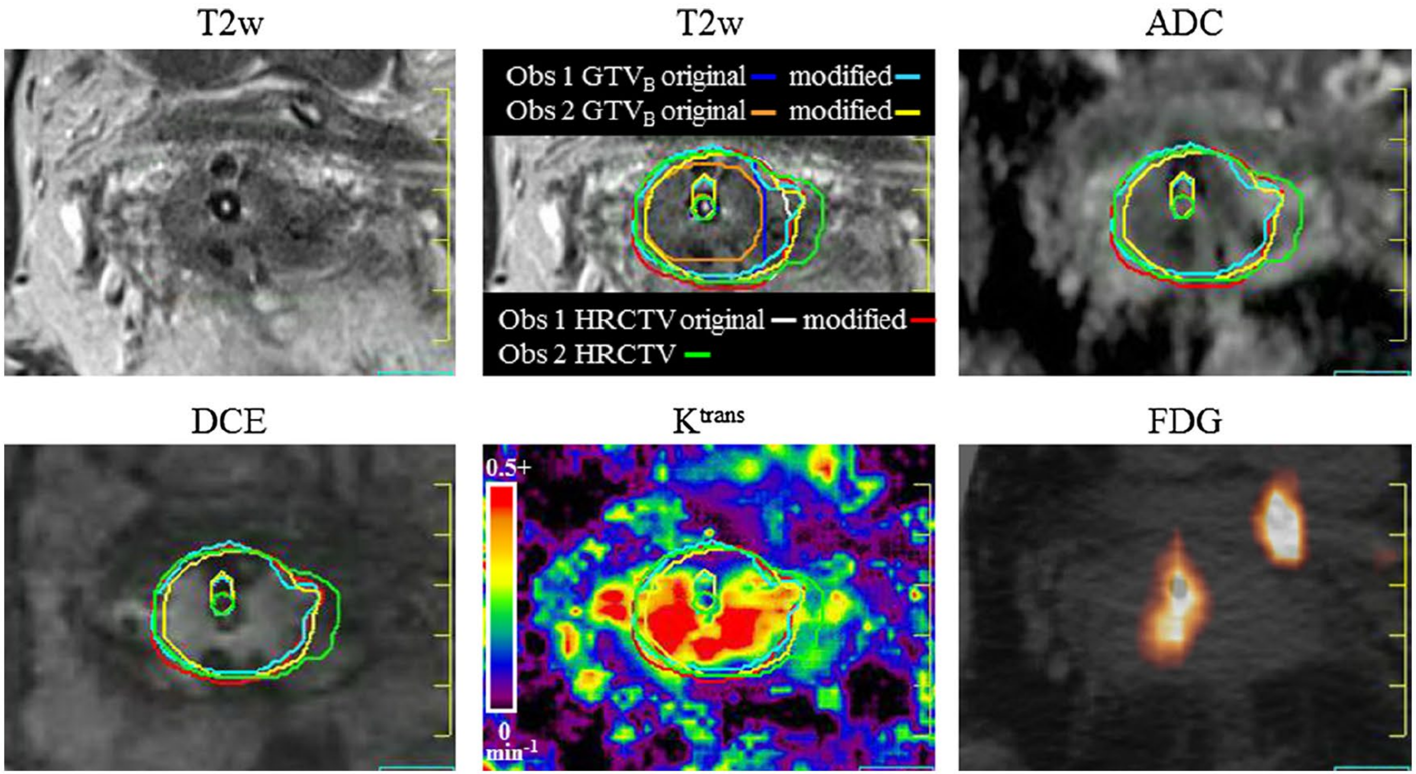

Fig. 2. Axial T2w MR and functional images of a patient with stage IIA cervical cancer at the time of brachytherapy. Both observers modified their T2w-derived GTV_B based on clearer demarcation of the left lateral extent of the tumor via restricted diffusion and early DCE-MRI enhancement. Observer 1 also modified the HRCTV to incorporate the left lateral extent of GTV_B that was not appreciated on T2w MR.

Han *et al.*, Radiother Oncol 2016;120:519-525.

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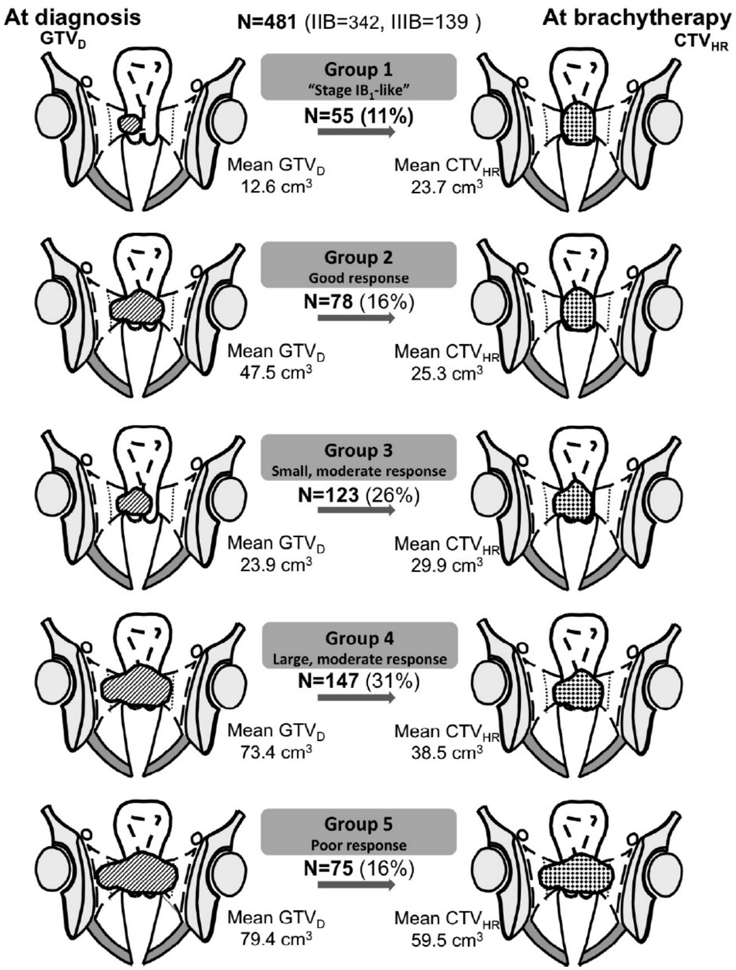
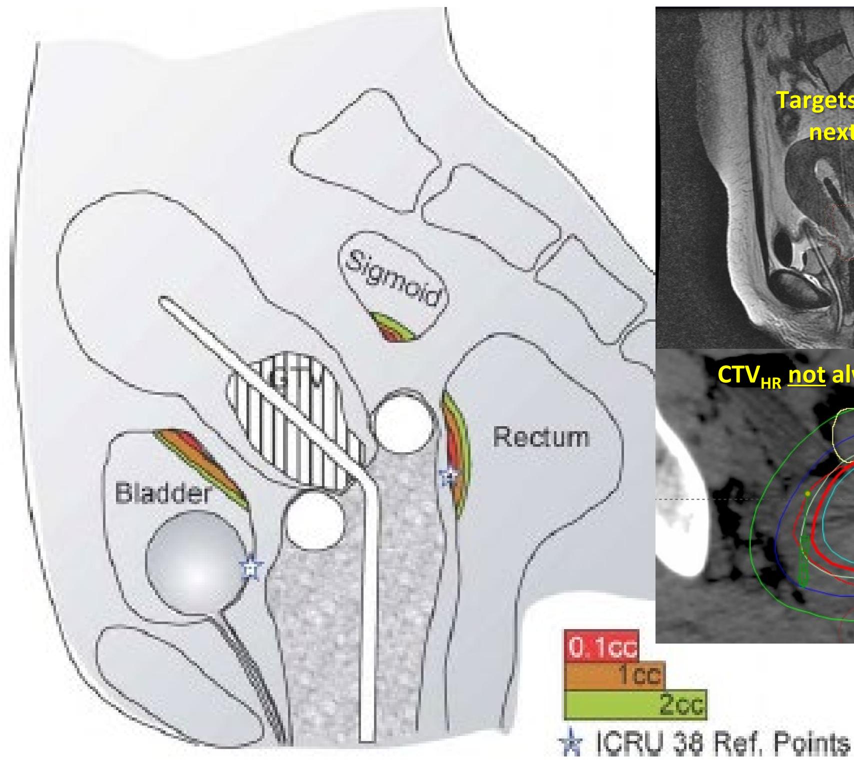
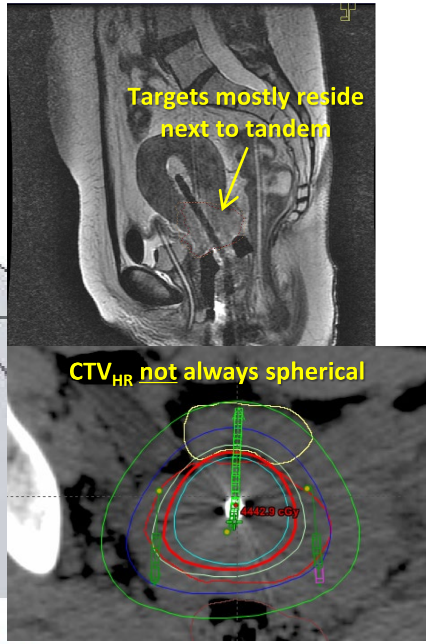
A Well-Suited Problem? Cervix



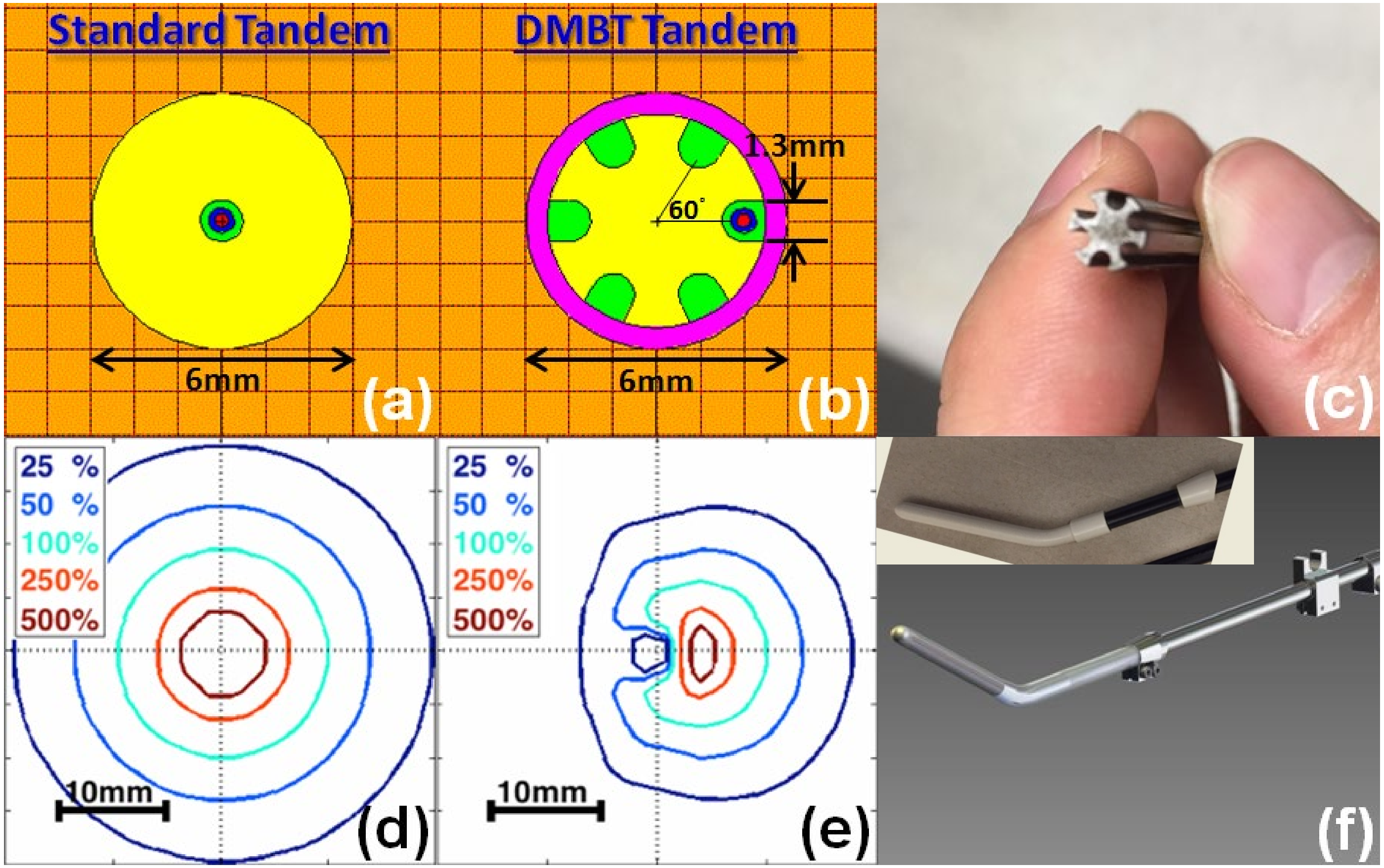
Jastaniyah *et al.*, Radiother Oncol 2016;120:404-411.





Potter *et al.*, Radiother Oncol 2006;78:67-77.

DMBT Design



Han *et al.*, Int J Radiat Oncol Biol Phys 2016;96(2):440-448.

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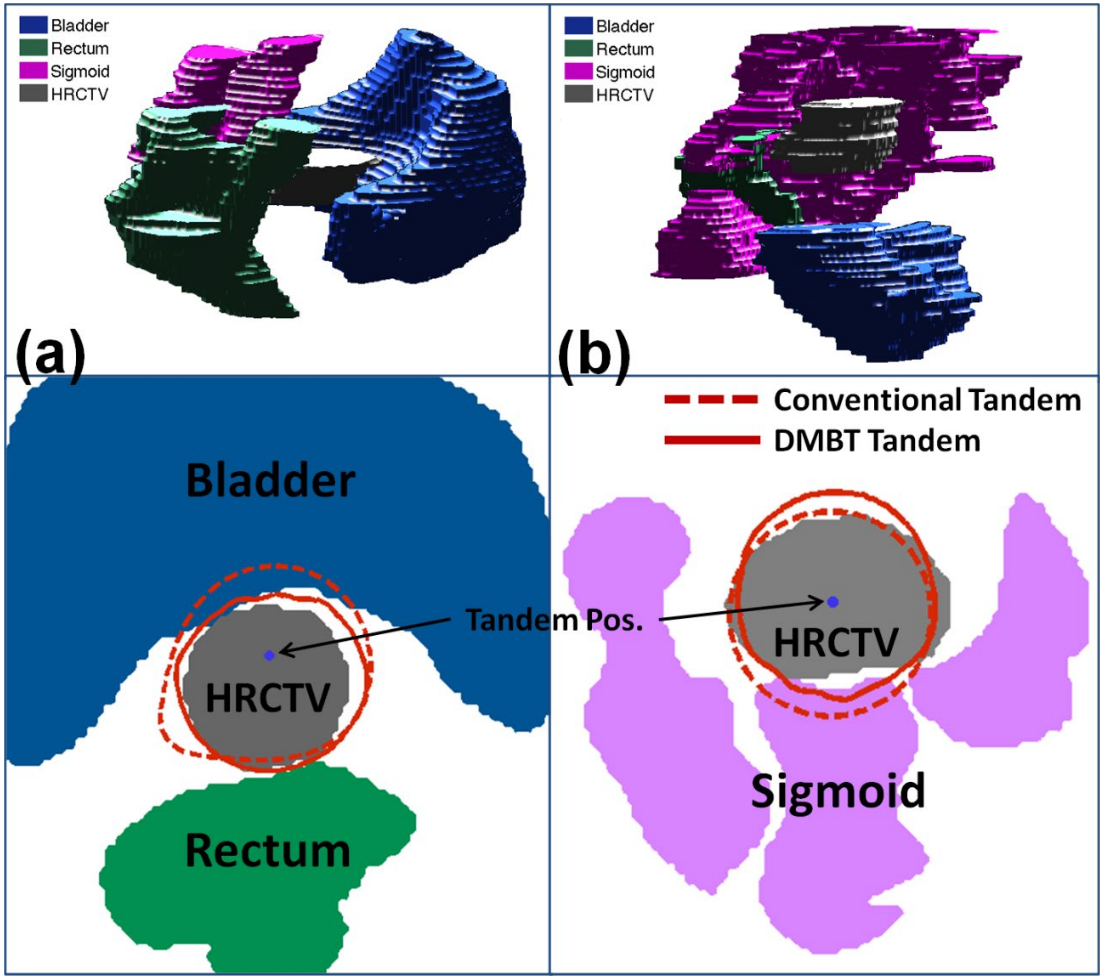
T&O vs DMBT



Han *et al.*, Int J Radiat Oncol Biol Phys 2014;89:666-673.

On average, D_{2cm3} reductions for 75 plans from UCSD:
Bladder 8.5% ± 28.7%
Rectum 21.1% ± 27.2%

Best single-plan reductions:
Bladder 40.8%
Rectum 40.1%

Shield Selection

Table 1. Susceptibilities of water, tissue, and selected materials [25,44,49,68]

Material	Density (g/cm³)	Susceptibility (ppm)
Gold	19.3	–34
PEEK	1.3	–9.33
Water (37°)	0.933	–9.05
Human tissues	~0.92-1.05	~(–11.0 to –7.0)
Air (NTP)	1.29×10^{-3}	0.36
Aluminum	2.7	20.7-20.9
Tungsten	19.3	77.2-80
Titanium	4.54	182
Stainless steel (nonmagnetic, austenitic)	8.0	3520-6700

PEEK – polyether ether ketone, NTP – normal temperature [20°C] and pressure [101.325 kPa]

Soliman *et al.*, J Contemp Brachy 2016;8(4):363-369.

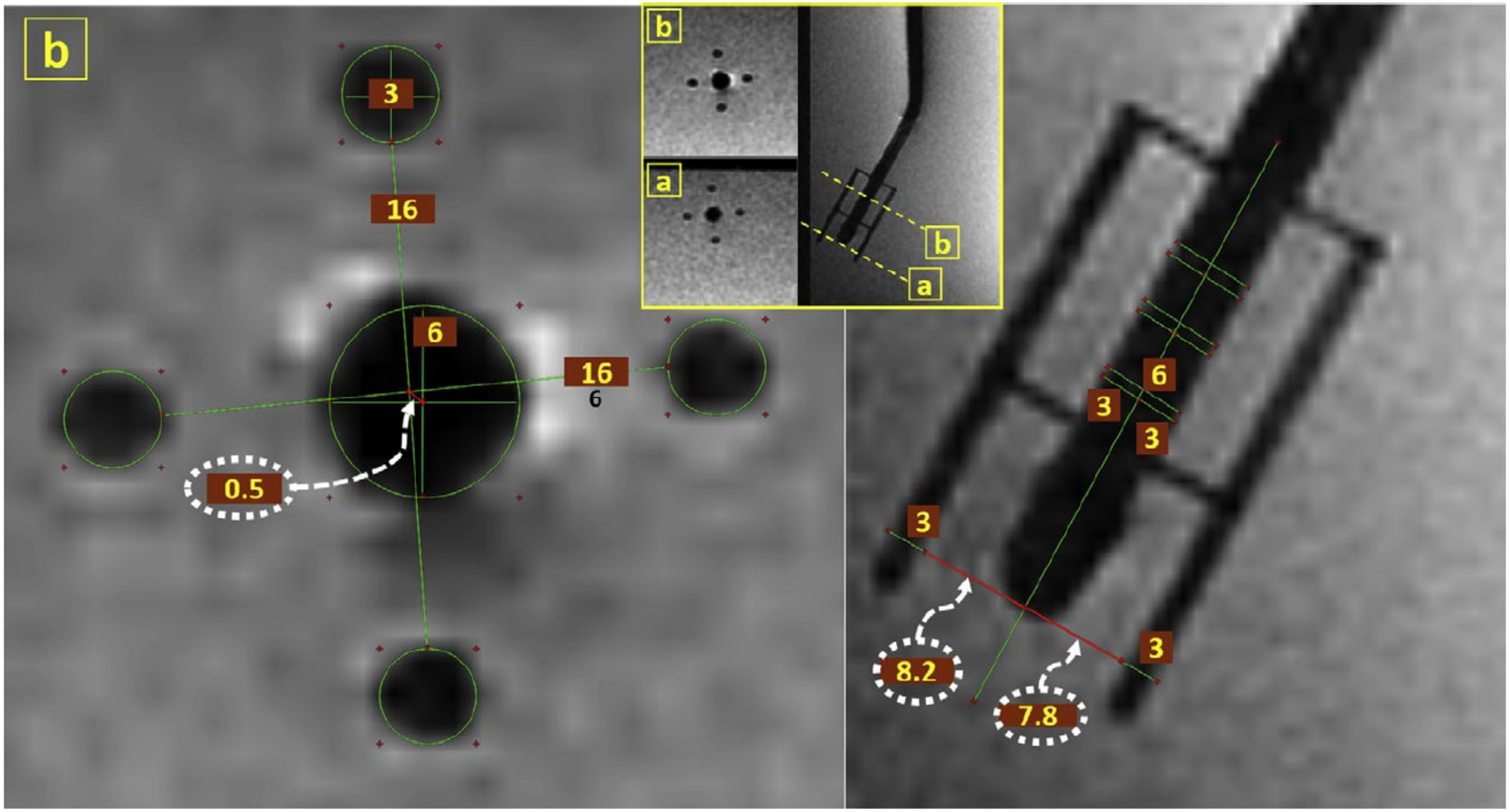
List of sintered heavy tungsten alloy samples in the market:

Sample	Elemental composition (wt.%) W	Fe	Ni	Cu	Grade
F_xN_x	...	...	...	...	MLC
$F_{3.0}N_{7.0}$	90.0	3.0	7.0	0.0	MT17F[a]
$F_{1.5}N_{3.5}$	95.0	1.5	3.5	0.0	MT18F[a]
$F_{1.5}N'_{3.5}$	95.0	1.5	3.5	0.0	HE395[b]
$F_{0.9}N_{2.1}$	97.0	0.9	2.1	0.0	MT185[a]
$F_{0.0}N_{6.0}$	90.0	0.0	6.0	4.0	MT17C[a]
$F_{0.0}N_{4.0}$	95.0	0.0	4.0	1.0	HA195[b]
$F_{0.0}N_{3.5}$	95.0	0.0	3.5	1.5	MT18C[a]

Kolling *et al.*, Med Phys 2014;41(6):061707.

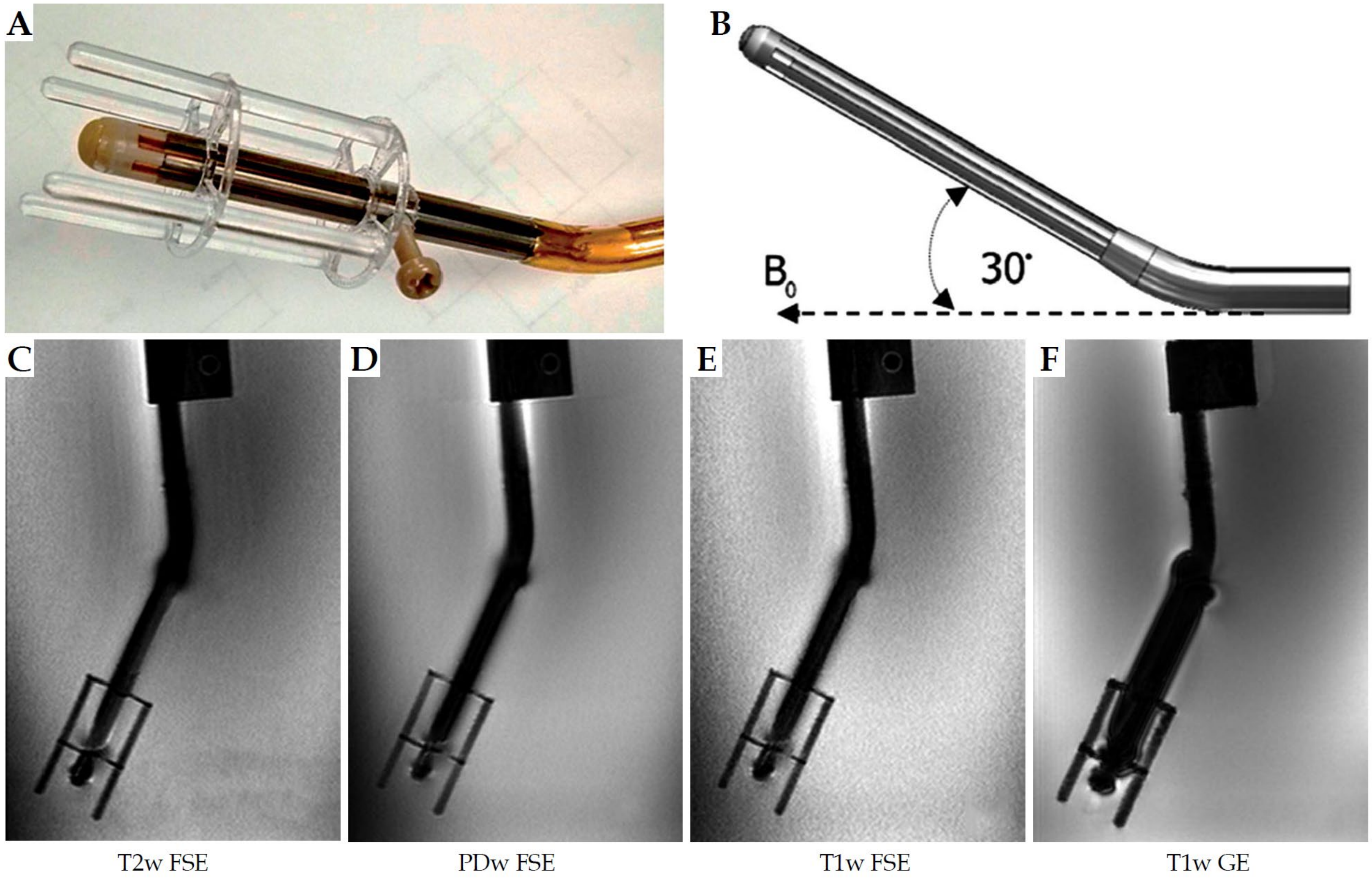
- Density = 18.0 g/cm³ (high)
- W is (weakly) paramagnetic
- Ni is (weakly) ferromagnetic
- Fe is (strongly) ferromagnetic

1.5T MRI



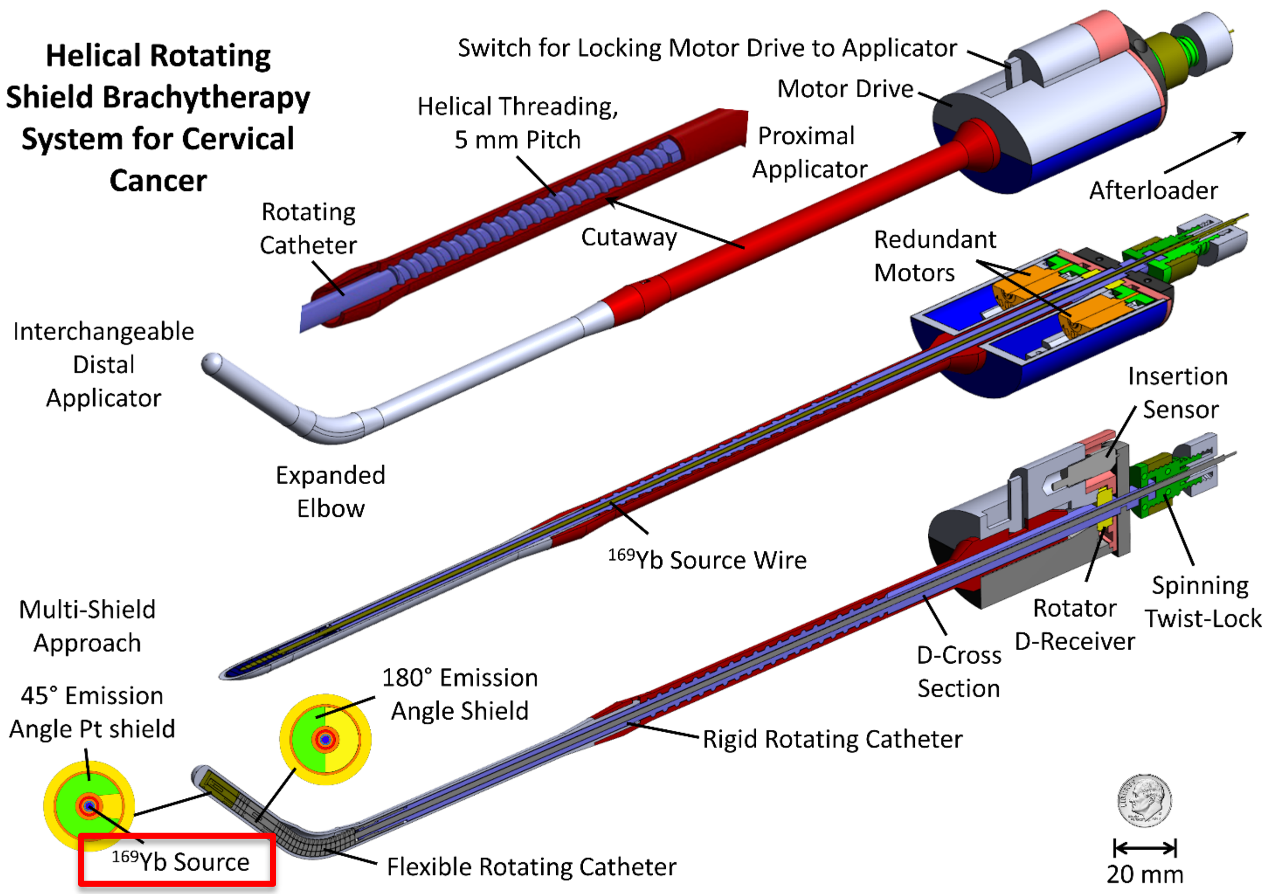
Soliman *et al.*, Radiother Oncol 2016;120(3):500-506.

3T MRI



Soliman *et al*., J Contemp Brachy 2016;8(4):363-369.

Dr Ryan Flynn's Lab - RSBT



Hopfensperger KM, *et al.*, Med Phys 2020;47:2061-2071.

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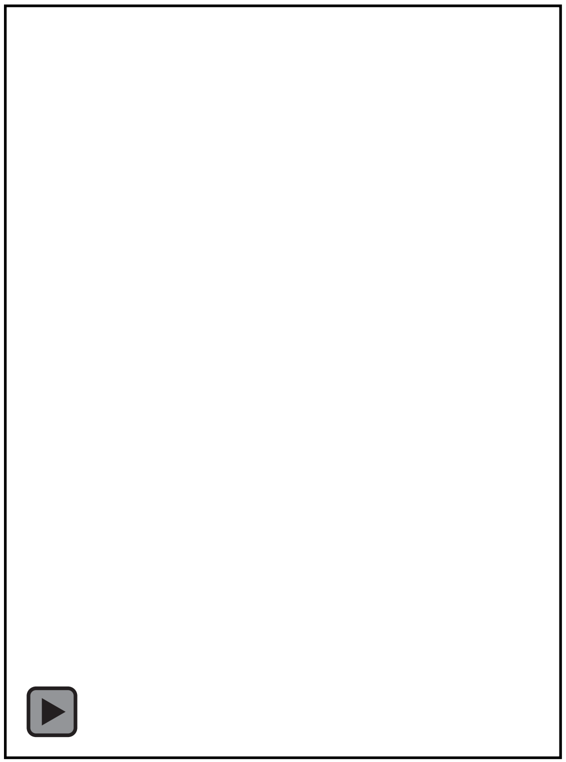
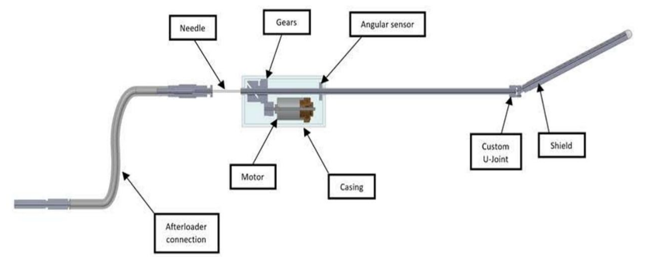
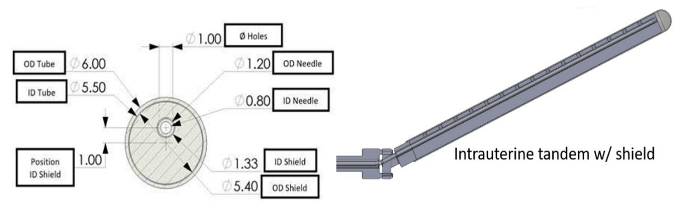
Dr Shirin Enger's Lab - IMBT







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Original paper

Monte Carlo dosimetry study of novel rotating MRI-compatible shielded tandems for intensity modulated cervix brachytherapy

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[b] Department of Oncology, McGill University, Montreal, QC, Canada
[c] Research Institute of the McGill University Health Centre, Montreal, QC, Canada
[d] Department of Radiation Oncology and Molecular Radiation Sciences, Johns Hopkins University, Baltimore, MD, USA

Dr Jungwon Kwak's Lab

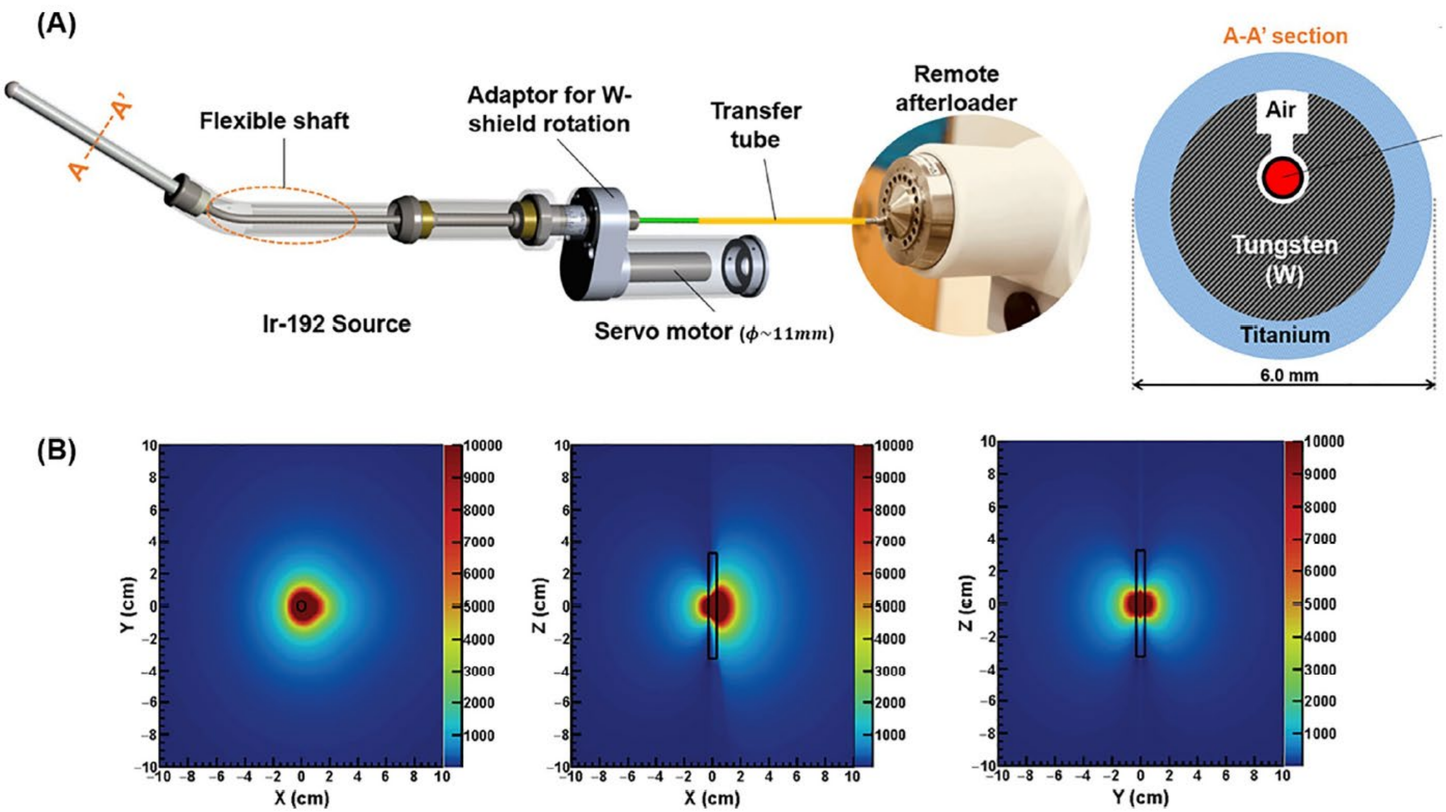

Fig 1. Novel rotatable tandem applicator and estimated dose distribution. (A) Novel, rotatable tandem applicator. (Bottom) Monte-Carlo-simulated dose distribution in water medium for ^{192}Ir radiation source with the new tandem applicator, which is orthogonal to the axial plane, irradiated to the left-hand side in the image plane.

Kim H, *et al.*, PLoS ONE 2020;15(7):e0236585.

Dr Jooyoung Sohn

- 3D rapid printing solution
- Use with a Smit Sleeve

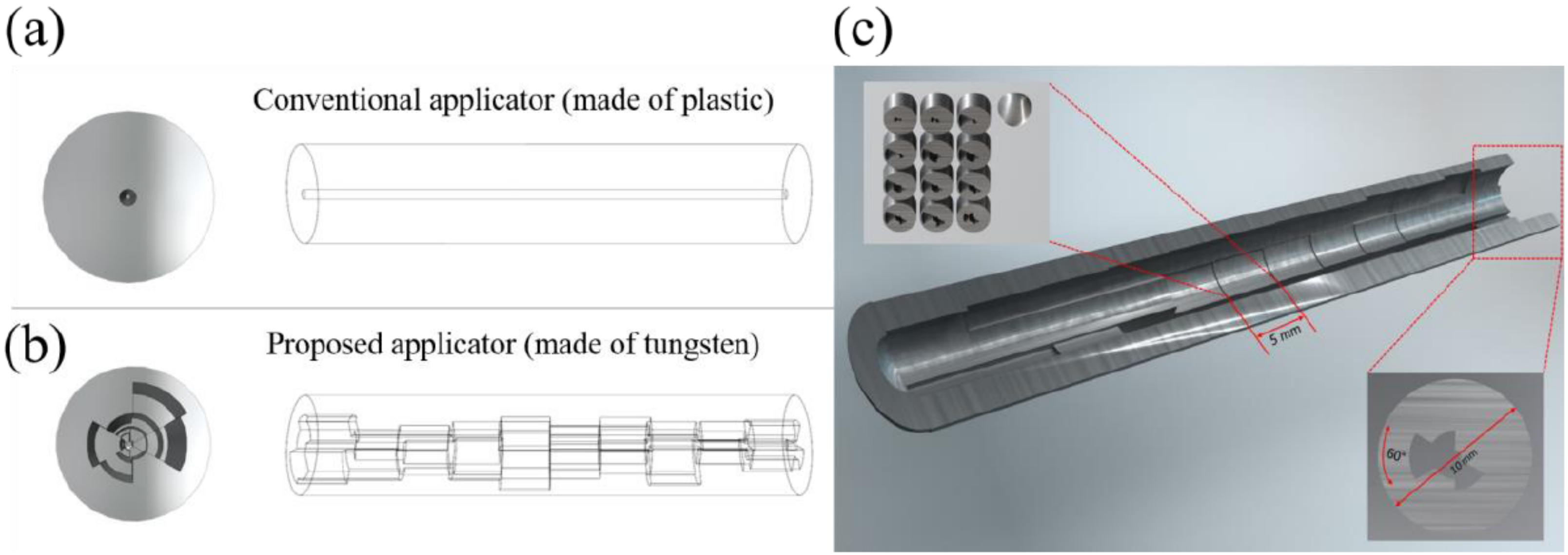

Figure 1. A conceptual diagram of our prosed applicator that differs with the conventional applicator. (a) is the conventional HDR method, and (b) is the proposed HDR method, and (c) is the inside view of the whole applicator. Each dwell position has 5 mm length and the cross-section has a different shielding thickness per 60-degree angle.

Sohn, Jooyoung, *et al.*, Manuscript Under Preparation, 2021.

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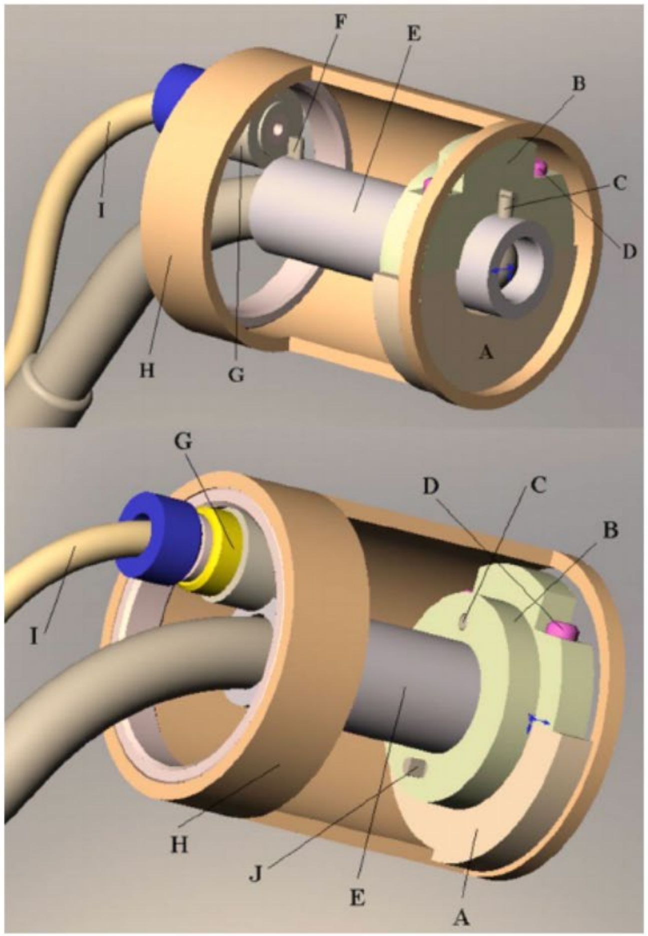
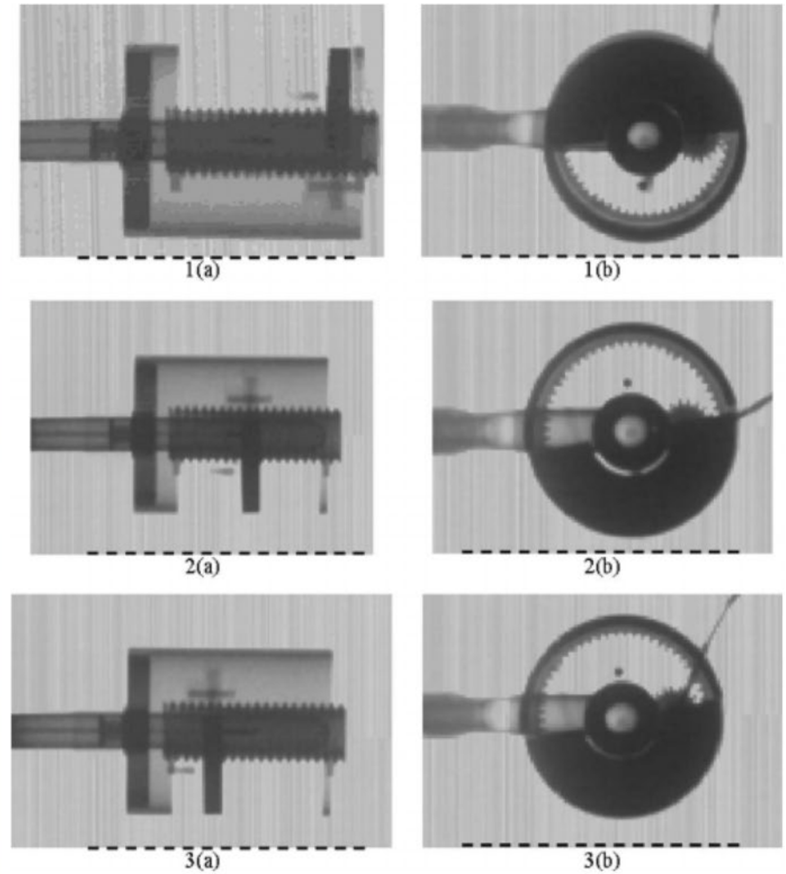
Dr Firas Mourtada's Lab





Price MJ, *et al.*, Med Phys 2009;36(9):4147-4155.

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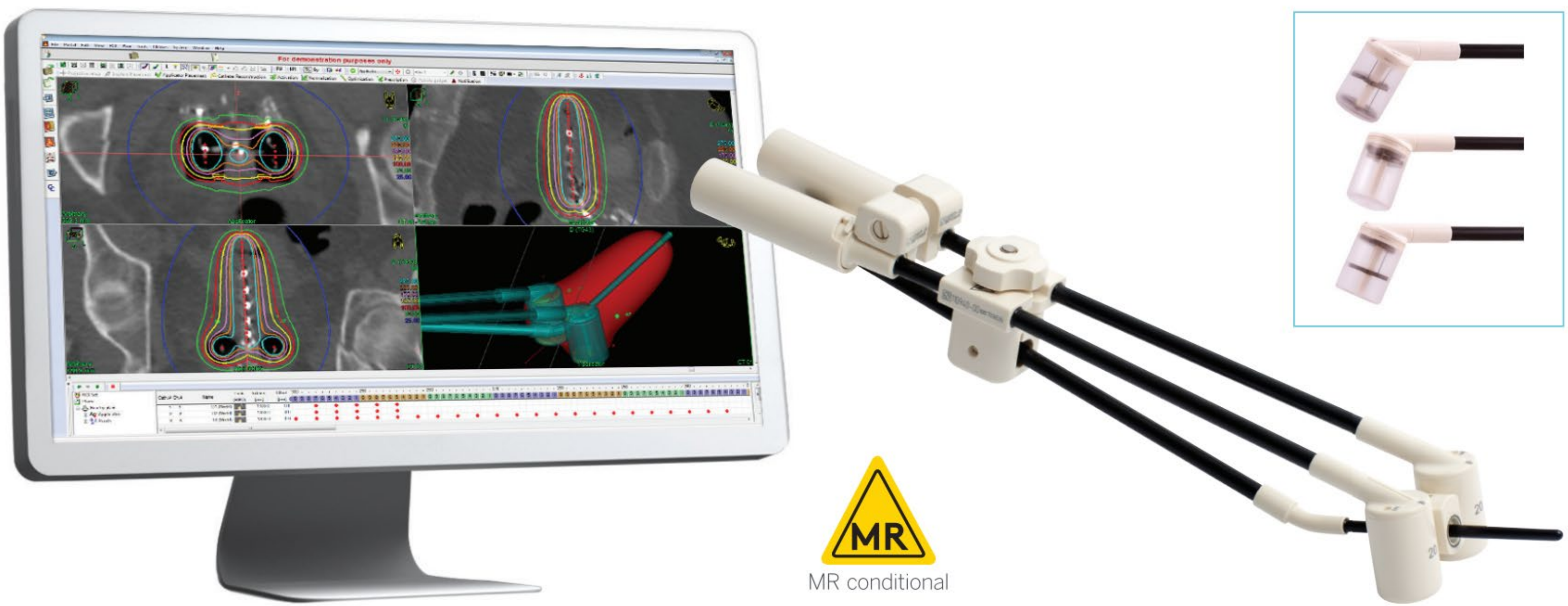

Image shows the applicator with the 4 mm intrauterine tube

Fletcher CT/MR Shielded Applicator

https://www.elekta.com/dam/jcr:5fd34853-7bf3-48ba-8830-68250797bb39/Brachytherapy-Applicator-Guide.pdf

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TG43 → TG186 (MBDCA)

- TG43 – *Homogeneous water medium*
- TG 186 – *Came out in 2012*

Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: Current status and recommendations for clinical implementation

Luc Beaulieu[a)]
Département de Radio-Oncologie et Centre de Recherche en Cancérologie de l'Université Laval, Centre hospitalier universitaire de Québec, Québec, Québec G1R 2J6, Canada and Département de Physique, de Génie Physique et d'Optique, Université Laval, Québec, Québec G1R 2J6, Canada

Beaulieu *et al*., Med Phys 2012;39(10):6208-6236.

- **Model Based Dose Calculation Algorithms**
  1. Monte Carlo (RayStation®; *in progress*)
  2. Collapsed Cone Convolution (ACE®)
  3. Grid Based Boltzmann Solver (AcurosBV®)

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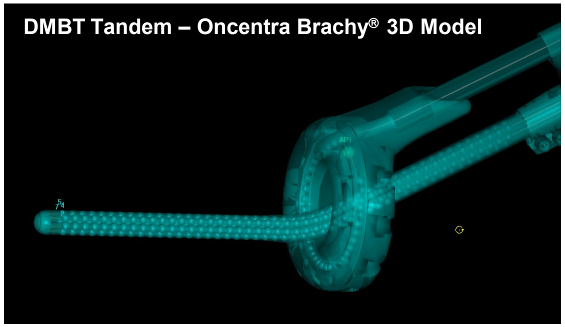
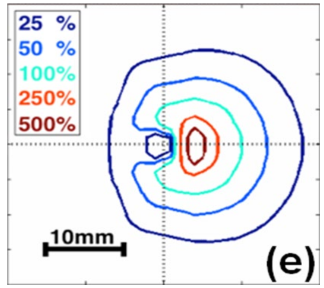
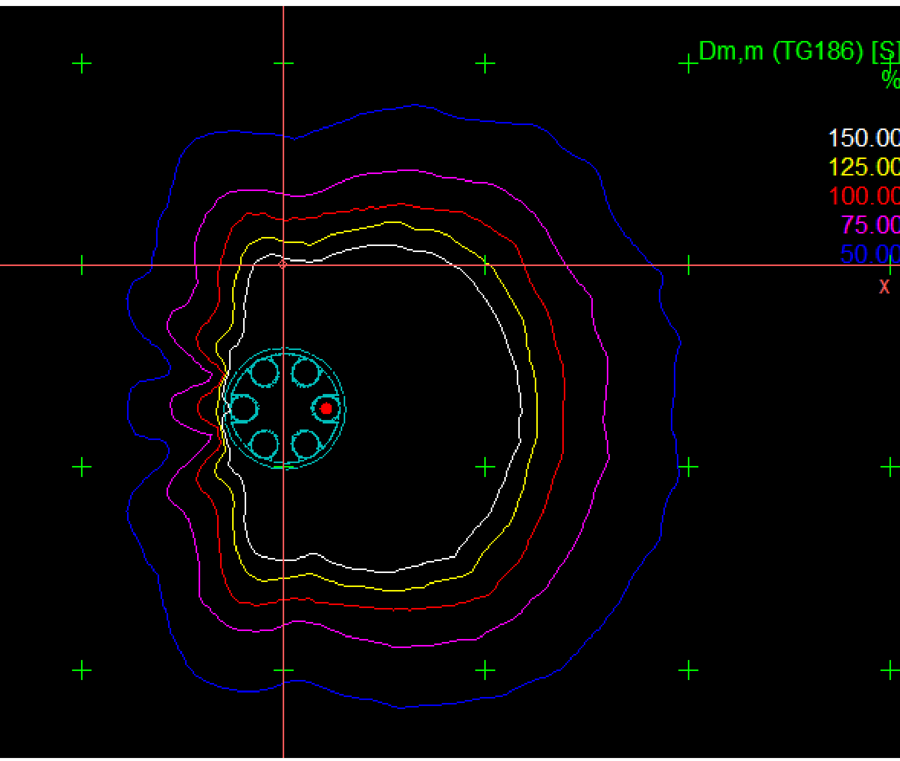
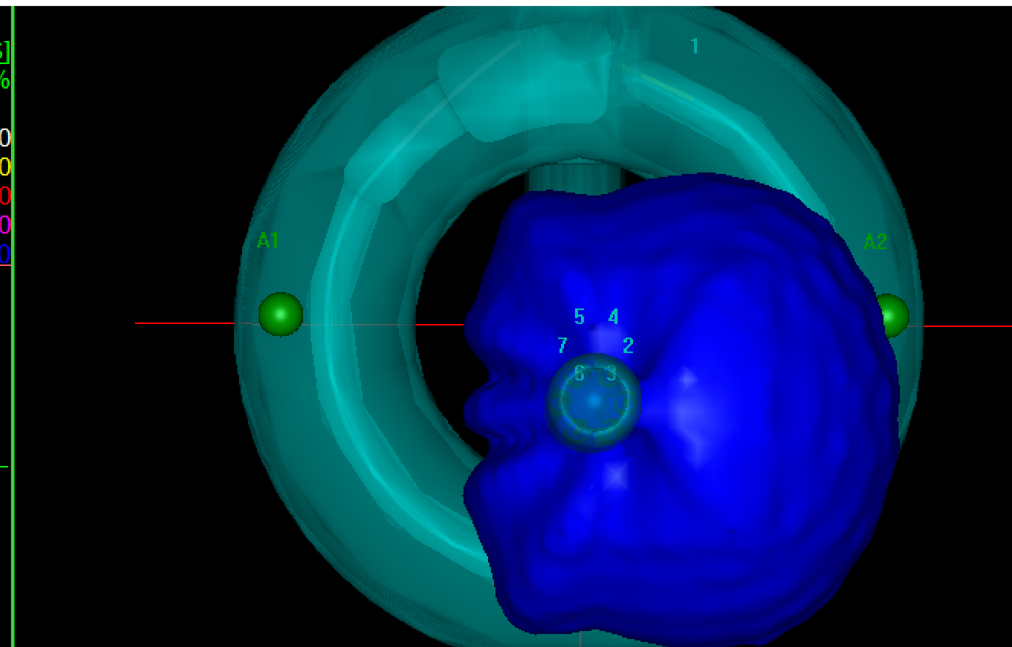
Oncentra Brachy®





Han *et al.*, Int J Radiat Oncol Biol Phys 2016;96(2):440-448.

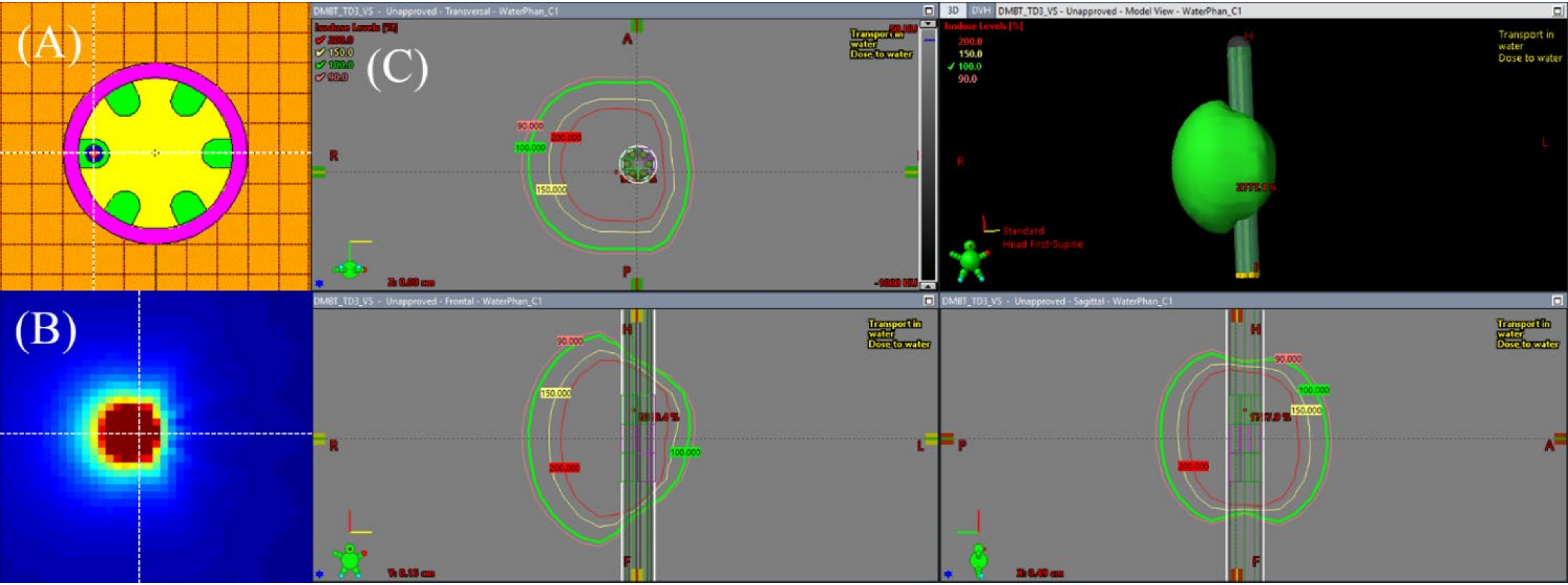




- 3.5% mean dose difference
- Range: 0.1 – 6.5%

Safigholi *et al.*, Brachytherapy 2018;17:1030-1036.

BrachyVision®



Sohn, Jooyoung, *et al.*, Manuscript Under Preparation, 2021.

Discussion

- IMABS developments have come a long way since Dr Ebert's landmark publication on IMBT, in 2002
- However, there's still some ways to go for many of the promising solutions to reach clinical commercialization, of which, heterogeneities are not an issue for dose calculations (TG186) or MR compatibility, at least
- It is projected that EMT dwell-position verification, in-vivo dosimetry, real-time source tracking, etc. are all important components of IMABS' treatment delivery & QA
- Ultimately, TG100 should be performed to establish optimal workflow & QA, which are unique to each IMABS solution & site
- TG337 is actively working on the technological review & clinical recommendations

Questions?