Consequences of patient heterogeneities for intermediate energy sources in post-implant assessment of prostate brachytherapy plans

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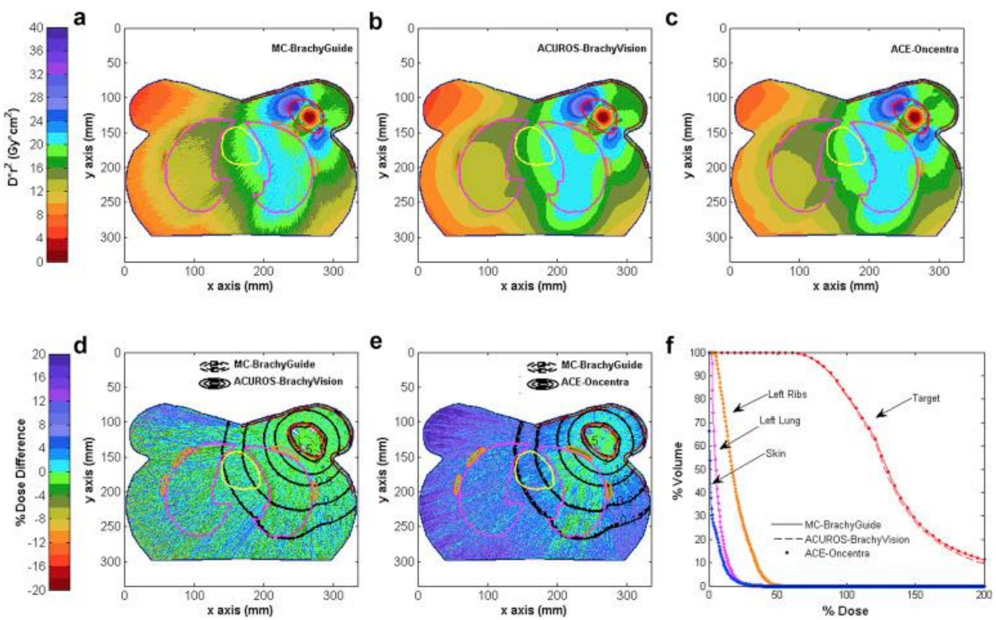
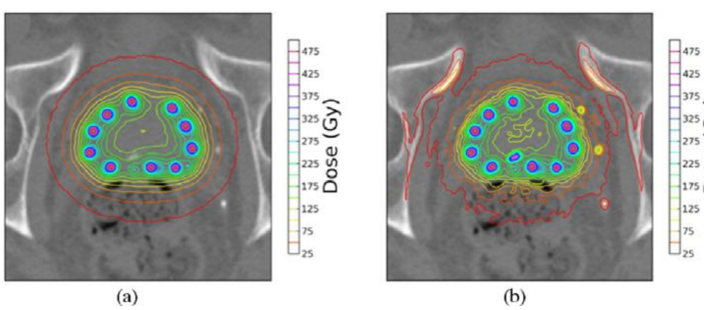
Heterogeneity corrections

Model-based dose calculation algorithms (MBDCA) are commercially available for brachytherapy dosimetry:



Peppa et al., 2016

- MC
- GBBS (ACUROS BV, Varian)
- CCC (ACE, Elekta)



Lemaréchal et al., 2015

MBDCA account for:

- Tissue heterogeneities
- Interseed attenuation
- Applicator heterogeneities (high-Z shielding)

Alternative HDR sources

Brachytherapy can be administered by:

- low energy sources (E < 50 keV) -> LDR
- intermediate energy sources (50 keV < E < 200 keV)
- high energy sources (E > 200 keV) -> HDR

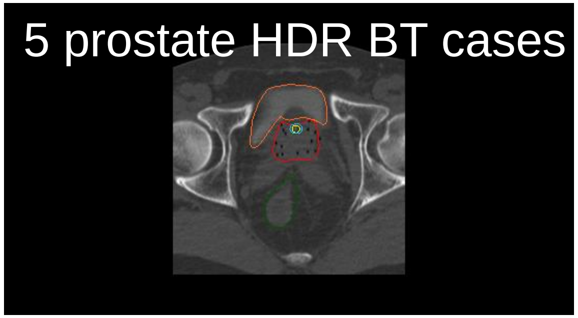
Recently, sources in the high (^{60}Co, ^{75}Se) and intermediate (^{169}Yb, ^{153}Gd) energy range have been proposed as alternatives to ^{192}Ir for HDR BT

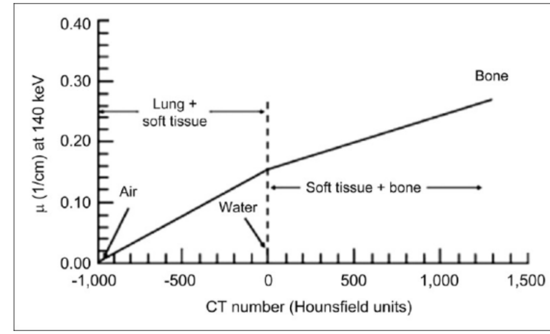
- Tissue composition and heterogeneities ignored -> errors in dosimetric indices

	^{60}Co	^{192}Ir	^{75}Se	^{169}Yb	^{153}Gd
Decay mode	β-	β-, IC	β-	β-	β-
Half-life (days)	1925	73.8	119.8	32.0	240.4
Mean γ energy (keV)	1250	360	210	93	60
HVL (mm Pb)	11	3	0.7	0.2	0.08
Activity to obtain $\dot{D}(r_0,\theta_0)$ A (Ci)	3.1	10	-	3.1	180

Aim: Determine the impact of tissue heterogeneities for alternative sources.

Materials and Methods





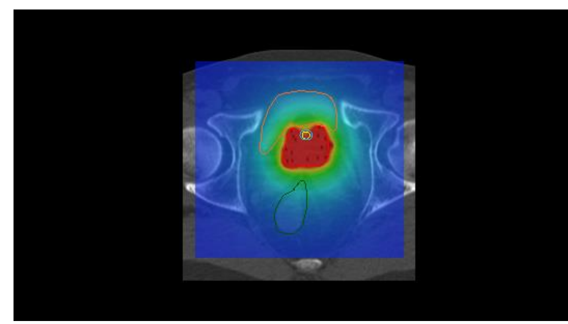
DICOM-RT
(CT, RS, RP, RD)

Geant4-based MC dose calculation engine

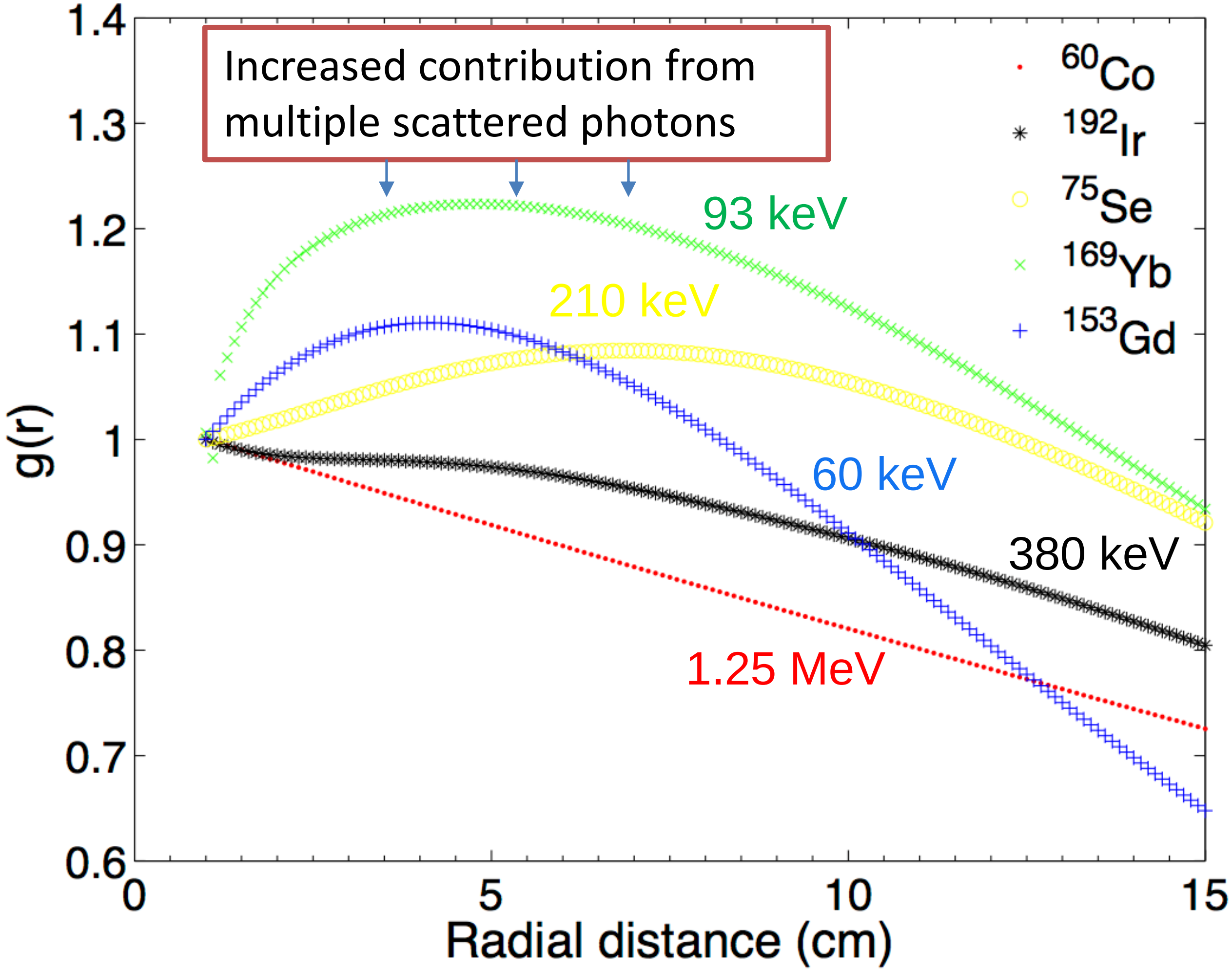
- Simulates nuclear decay
- Accounts for density and material composition of tissues, applicators, sources
- Track length estimator
- Variable scoring mesh

OUTPUT:
- $D_{w,w}$
- $D_{m,m}$

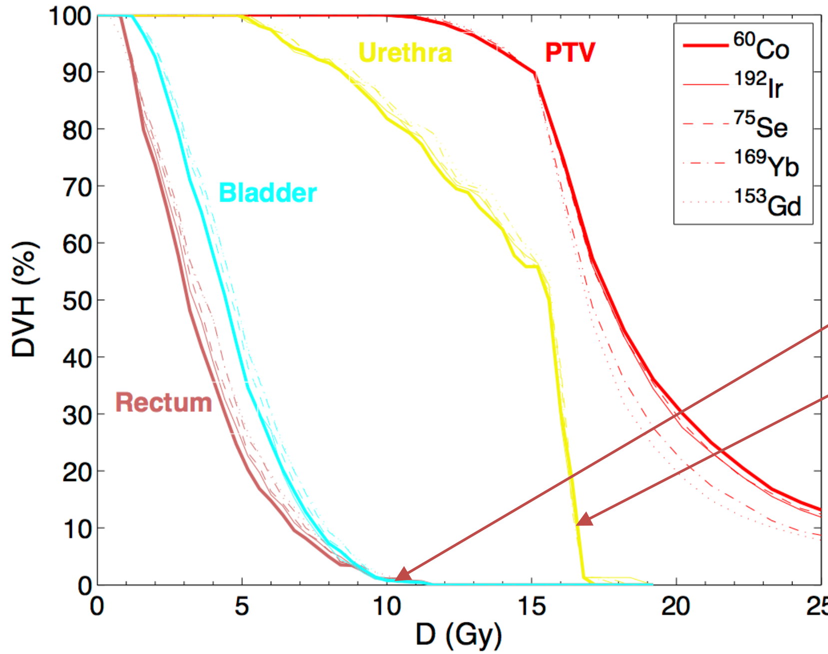
Column generation based optimizer



Source characteristics



Prostate case



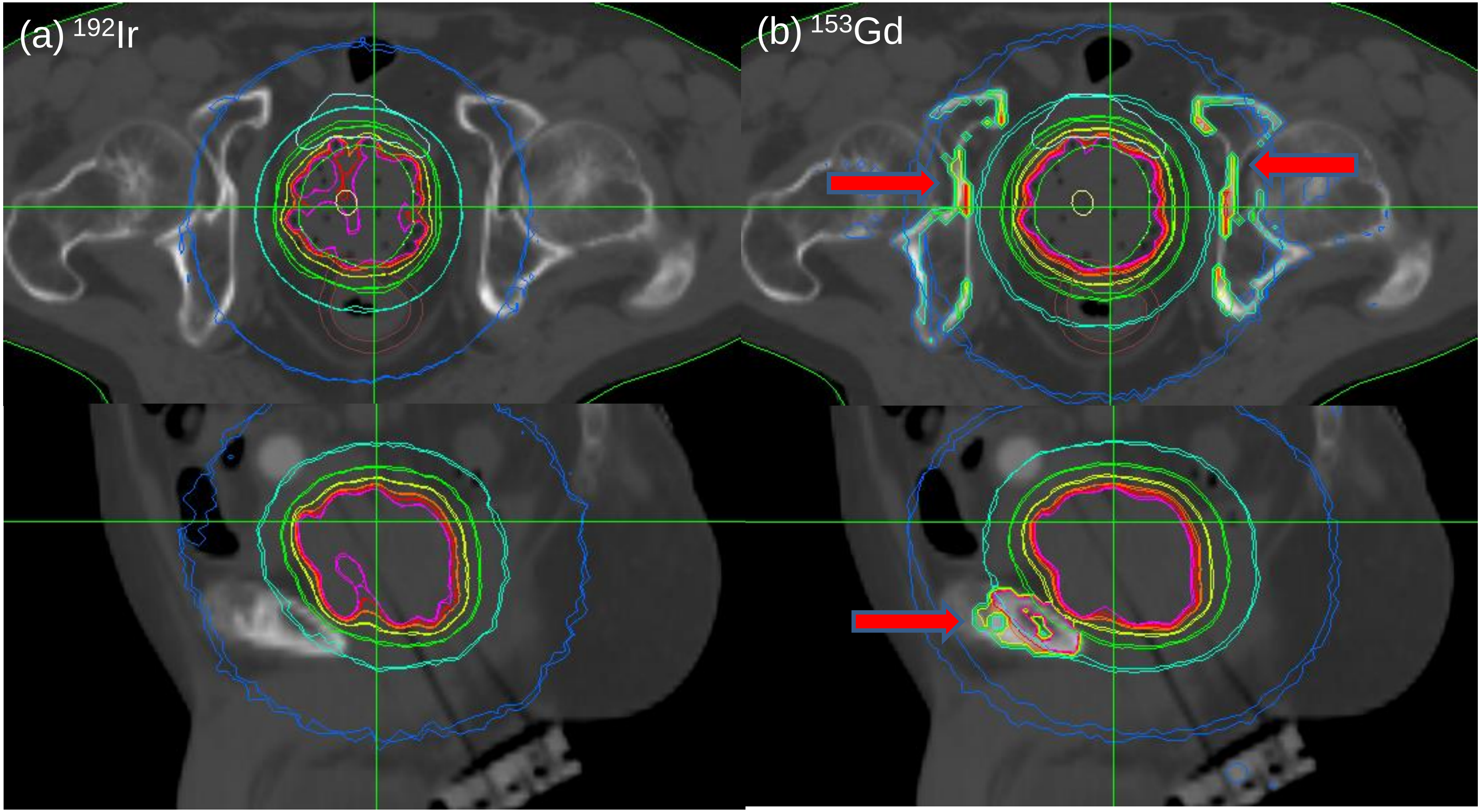
Structure	DVH Parameter	^{60}Co	^{192}Ir	^{75}Se	^{169}Yb	^{153}Gd
Prostate	D_{90} (Gy)	15.0	15.0	15.0	15.0	15.0
	V_{150} (%)	19.8	18	18.5	13.7	11.6
	DHI	0.780	0.800	0.794	0.848	0.871
Bladder	V_{75} (cc)	0.3	0.2	0.2	0.2	0.2
Rectum	V_{75} (cc)	0.2	0.2	0.2	0.2	0.2
Urethra	D_{10} (Gy)	16.5	16.5	16.5	16.5	16.5

DVH values for Monte Carlo simulated CT postimplant prostate plans. Plans were fully optimized for each source.

Advantages of intermediate energy sources:

- ✓ Optimal depth dose profiles (better target homogeneity)
- ✓ Reduced shielding requirements
- ✓ Suitable to deliver intensity modulated brachytherapy (IMBT)

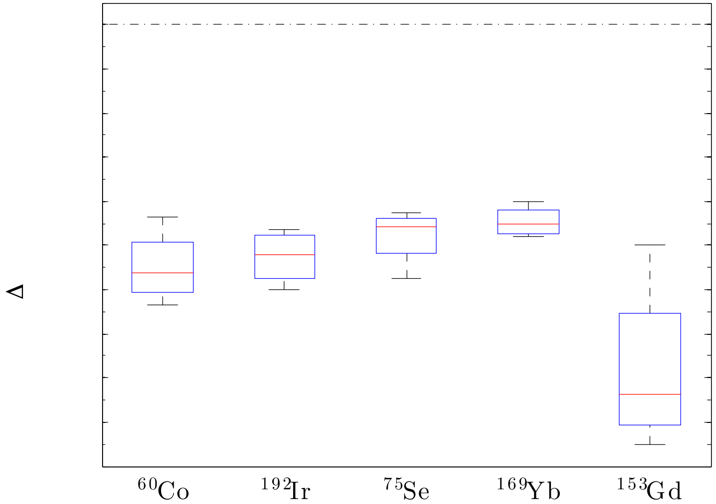
Dosimetric impact



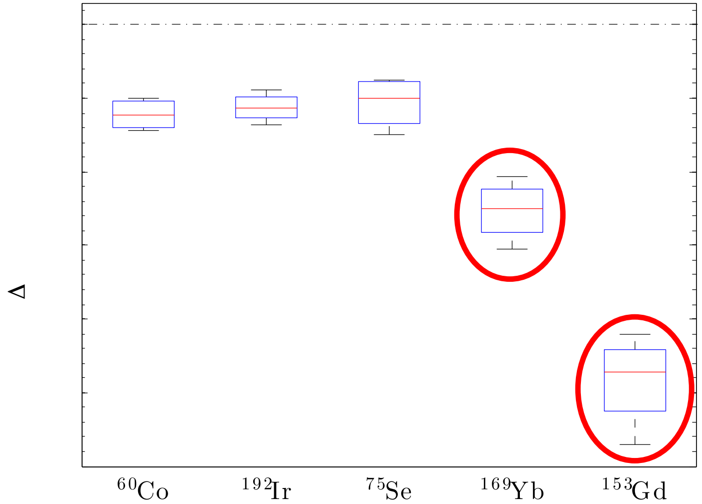
Dosimetric impact

Small impact on prescription dose

D_{90} PTV



D_{10} Urethra

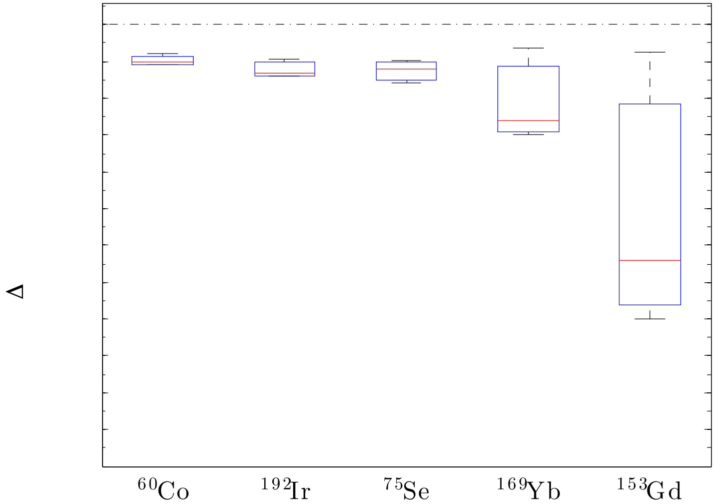


Reduction in urethral dose by 1-6%

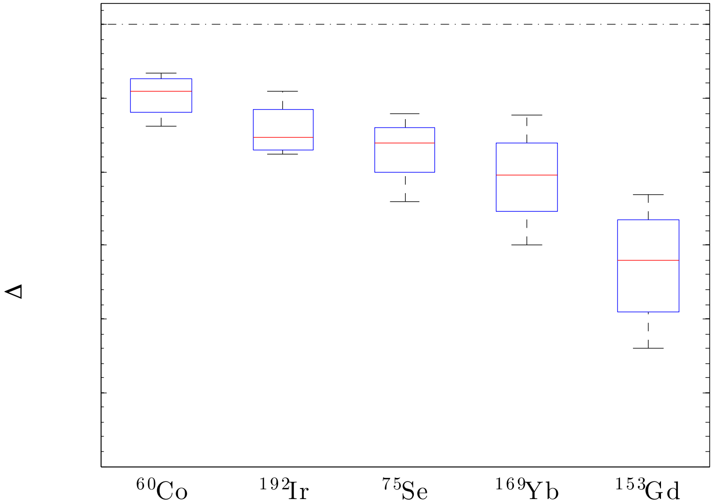
Dosimetric impact

Reduction in dose to bladder and rectum by 1-4%

D_{2cc} Bladder



D_{2cc} Rectum



Conclusions

- Intermediate energy sources have the potential to increase dose homogeneity within the PTV while limiting hot spots in the bladder, rectum and urethra.

- The ignorance of soft tissue heterogeneities resulted in overestimation of the dose delivered to OARs and underestimation of dose to bone.
  - Especially true for intermediate energy sources.

- There is still debate on whether differences are significant or not compared to other uncertainties in brachytherapy.
  - Dose delivery accuracy within ~5% (k=1)
  - Includes source-to-detector position, material composition, TPS, source specs

- Intermediate energy sources have yet to be introduced in the clinic…
  - … there is still time to implement and validate MBDCAs for intermediate energies.

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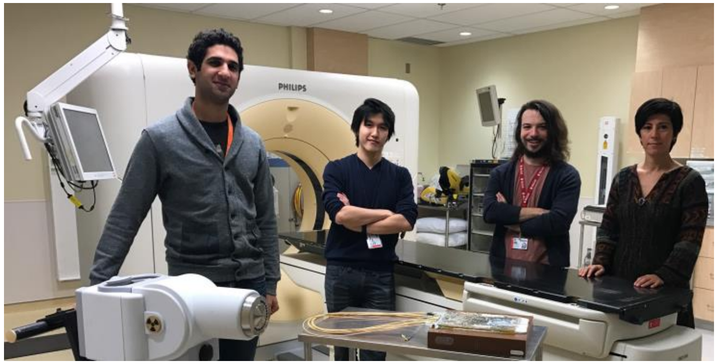

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