MicroMOSFET characterization for *in-vivo* dosimetry in brachytherapy.

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MEDICAL PHYSICS

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Research Article

Characterization of microMOSFET detectors for *in vivo* dosimetry in high-dose-rate brachytherapy with ^{192}Ir

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- IMPLEMENTATION IN CLINICAL PRACTICE (HUMV).

NECESSITY AND PURPOSE

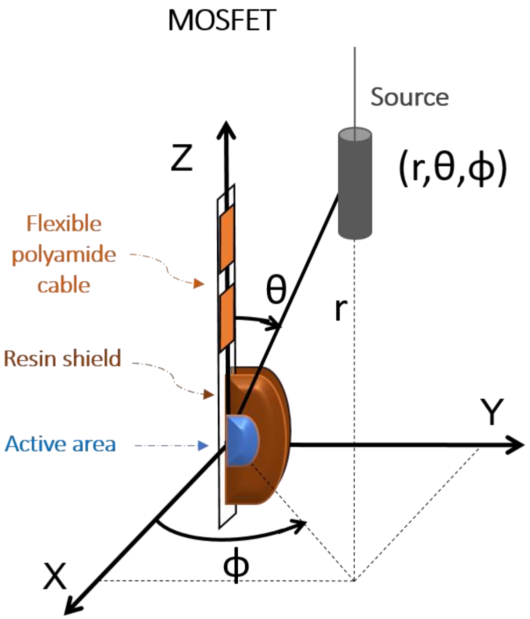
NECESSITY: The high doses per fraction and few fractions associated with this type of treatment motivated the implementation of *in-vivo* dosimetry (IVD) in order to verify the correct administration of the dose.

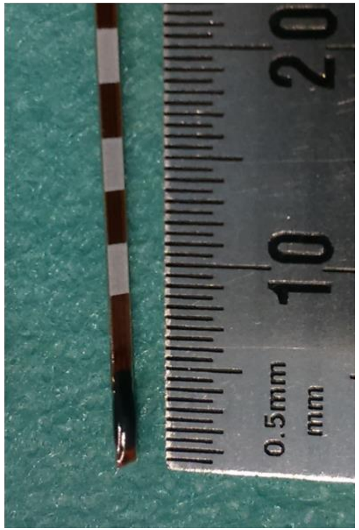
PURPOSE: characterization of microMOSFET detectors for IVD in high-rate prostate brachytherapy.

- Need for a corrective model.
- Proposal of model and validation of this.

DETECTORS DEPENDENCIES

Measurement system

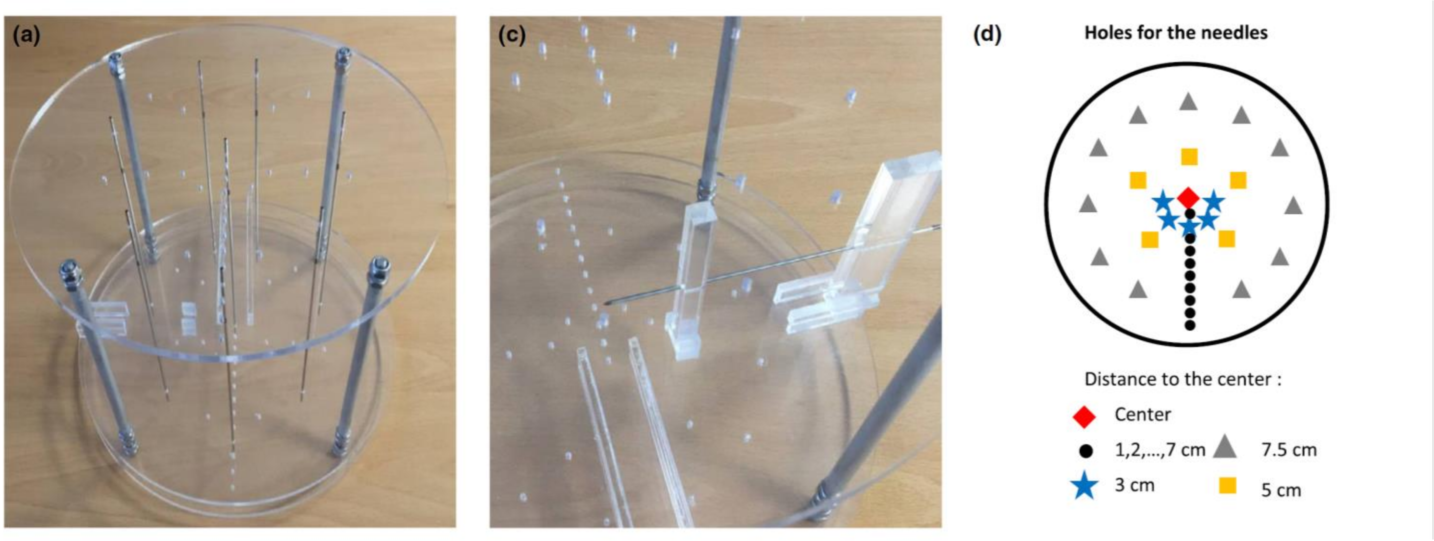




- MicroMOSFET TN-502RDM (Best Medical Canada).
- 1mm x 1mm x 3.5mm.
- Electrometer TN-RD-16: 5 simultaneous measurements.
- Elekta Steel Trocar needles of 1.9mm x 200mm.
- Flexitrón equipment y Flexisource source 192Ir (Elekta).
- Treatment Planning System (TPS): Oncentra® Prostate (Elekta).

Phantom

- Phantom for calibration and characterization of detectors.
- Measurements with the phantom submerged in water.



Calibration

- Calibration coefficient:

$$CF = [D(\vec{r}_0)/M(\vec{r}_0)]_{\mathrm{cal}}$$

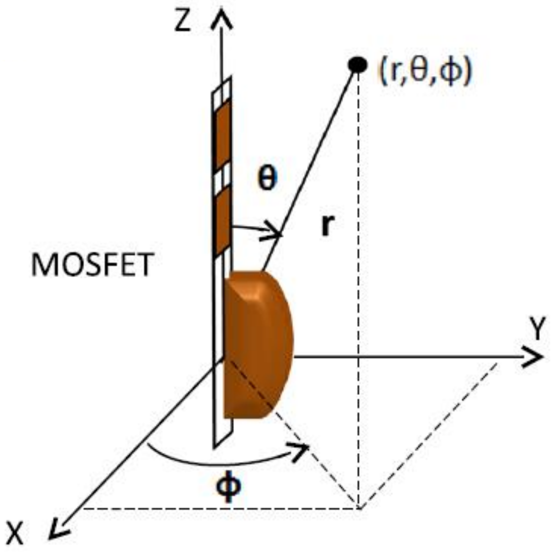
- Conditions:
  - T_0=294,15K
  - R_0=3 cm
  - Detector facing source
  - $D(r_0)$ =1Gy

- Reproducibility and intra-detector variation

Characterization

- Linearity
- Dependence with temperature
- Dependence with distance
- Angular dependency.

Angular dependency



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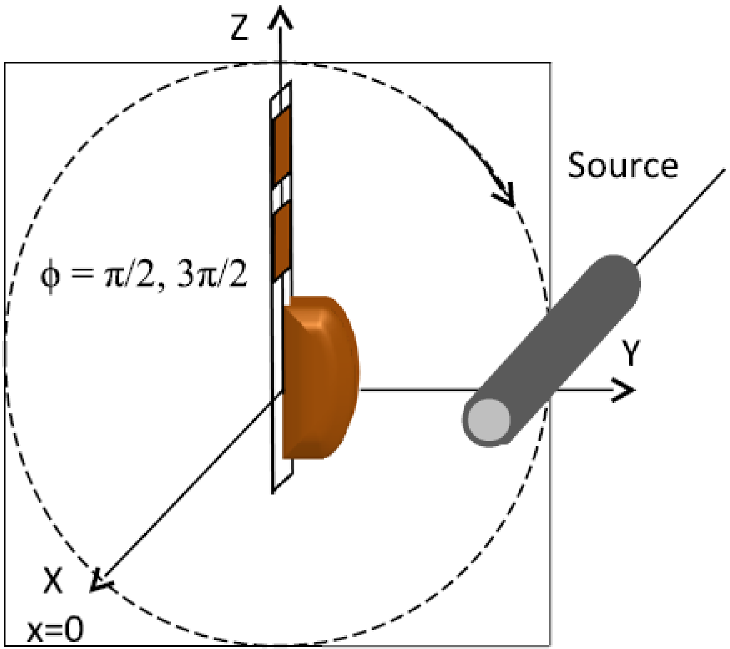

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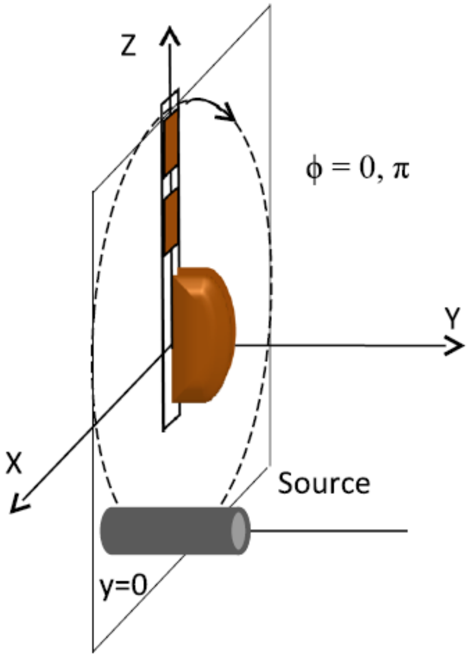

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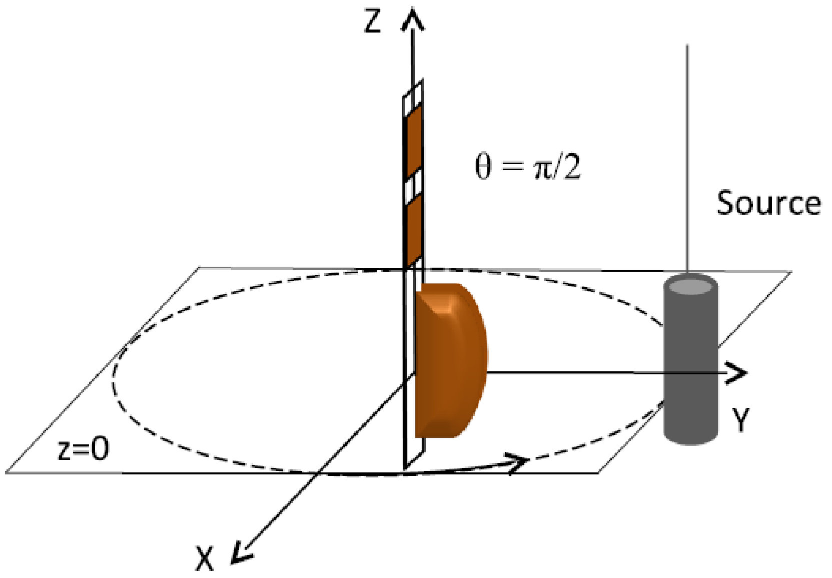


Correction model

- Relationship between the measurement of the microMOSFET and the absorbed dose in water:

$$D(\vec{r}) = CF \cdot f(T, r, \theta, \phi) \cdot M(\vec{r})$$

$$f(T, r, \theta, \phi) = f_1(T) \cdot f_2(r) \cdot f_3(\theta, \phi)$$

- Multiple stop positions of a source (real treatments):

$$D(\vec{r}) = \sum_{i=1}^{N} D_i(\vec{r}) = \sum_{i=1}^{N} CF \cdot f(T, r_i, \theta_i, \phi_i) \cdot M_i(\vec{r})$$

Correction model

- The TPS allows to obtain the dose contributions of each source stop at the measurement point. The absorbed dose at that point can be written:

$$D(\vec{r}) \sum_{i=1}^{N} \frac{D_i(\vec{r})}{D(\vec{r})} f(T, r_i, \theta_i, \phi_i)^{-1} = \sum_{i=1}^{N} CF \cdot M_i(\vec{r}) = CF \cdot M(\vec{r})$$

- The absorbed dose at the point of interest determined from the microMOSFET reading, and taking into account the correction model, is given by the following expression:

$$\boxed{D(\vec{r}) = F \cdot CF \cdot M(\vec{r})}$$

$$F = \left[\sum_{i=1}^{N} \frac{D_i(\vec{r})}{D(\vec{r})} f(T, r_i, \theta_i, \phi_i)^{-1} \right]^{-1}$$

Validation of the correction model

- Phantom to reproduce prostate brachytherapy treatments.
- Reproduction of 4 treatments with a prescription dose of 12Gy and 16 needles.
- 5 additional needles are inserted to place 5 microMOSFETs in the vicinity of:
  - left and right neurovascular bundle,
  - periurethral area,
  - rectal mucosa.
- 19 microMOSFET measurements to compare with the TPS dose.

RESULTS

Calibration and reproducibility

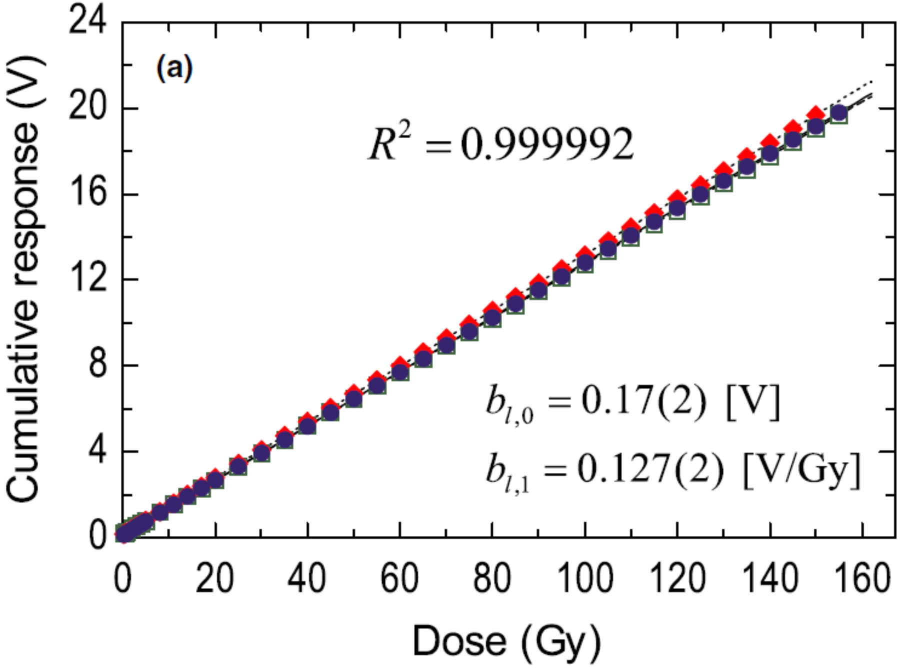
microMOSFET	1	2	3
$\overline{M}_j(\times 10^{-1}\ \mathrm{V})$	1.22(2)	1.10(2)	1.16(2)
$CF_j(\mathrm{cGy/mV})$	0.82(2)	0.91(2)	0.86(4)
Reproducibility (%)	2.3		
Variation inter-detector (%)	2.7		

Uncertainty

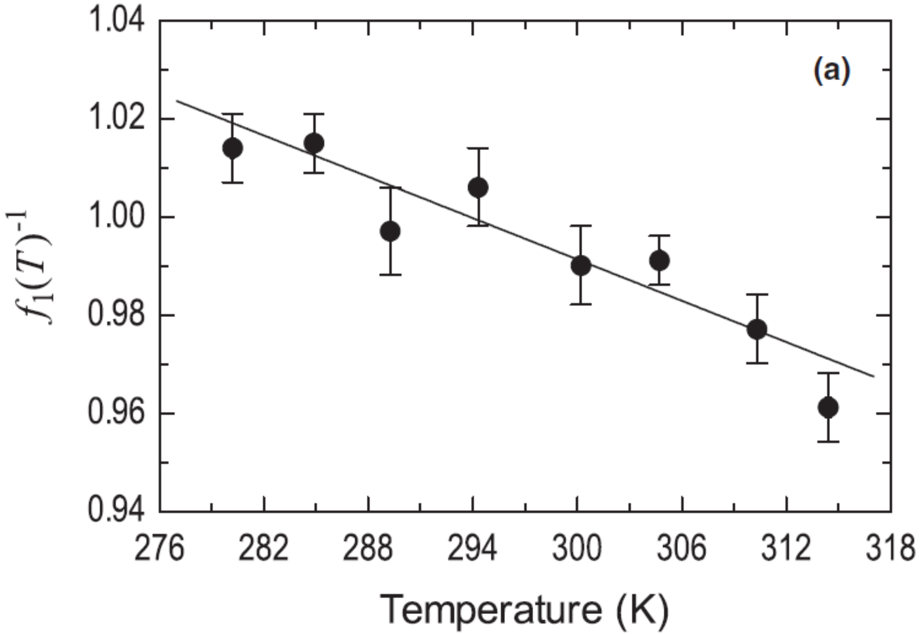
- Contributions to the global uncertainty of the calibration coefficient (k=1)

Sources of uncertainty	Uncertainty (%)
Air Kerma Strength (S_K)	1.5
TPS interpolation	2.6
Source to microMOSFET distance	2.0
Resolution of electrometer	0.009
Reproducibility	2.3
Phantom size	1.0
Positioning of the detector	1.5
Total uncertainty of *CF**	4.4
Total uncertainty including correction	4.6

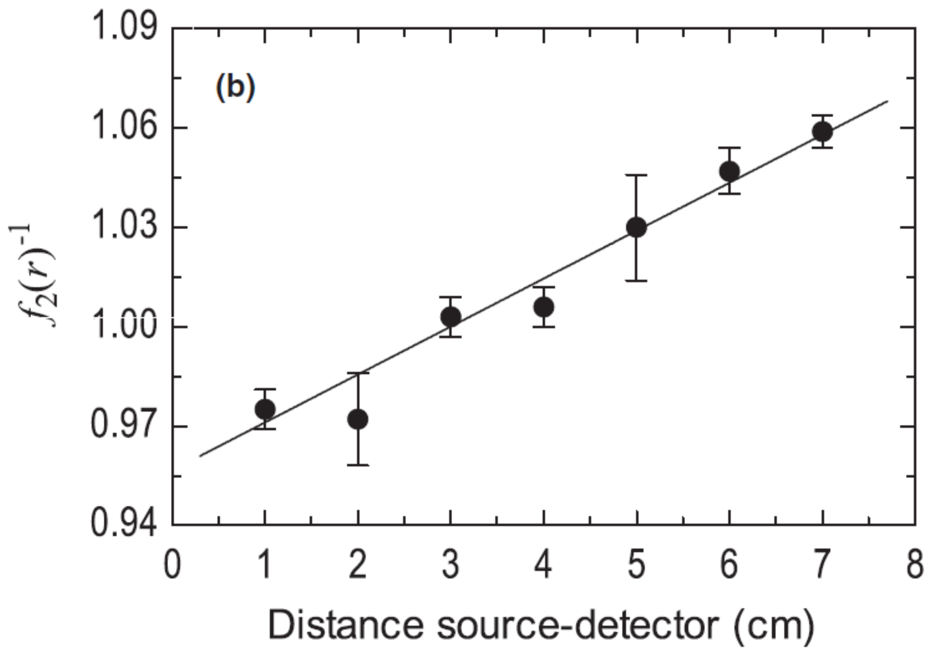
Linearity


(a)
$R^2 = 0.999992$
$b_{l,0} = 0.17(2)$ [V]
$b_{l,1} = 0.127(2)$ [V/Gy]
Cumulative response (V)
Dose (Gy)
0
4
8
12
16
20
24
0
20
40
60
80
100
120
140
160

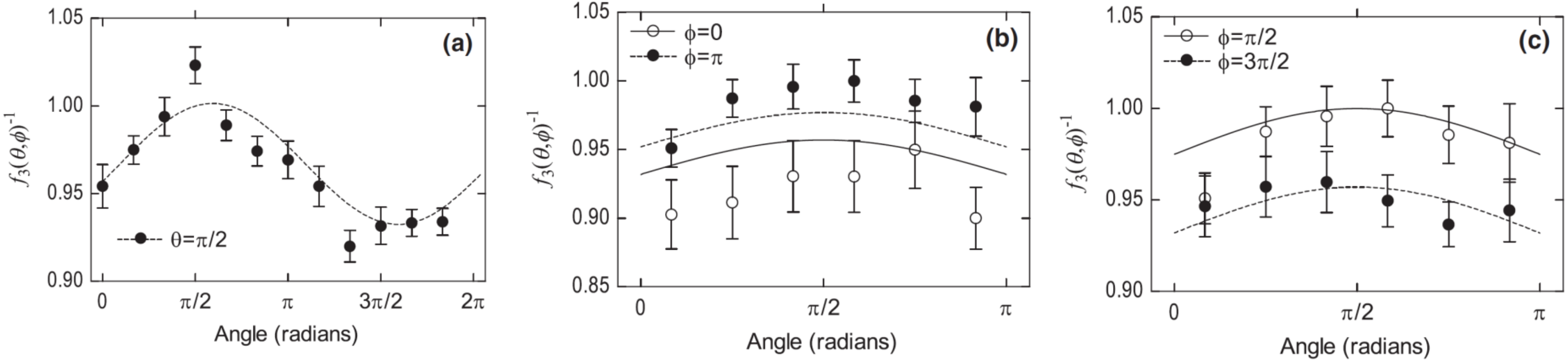
Temperature dependency



Distance dependency

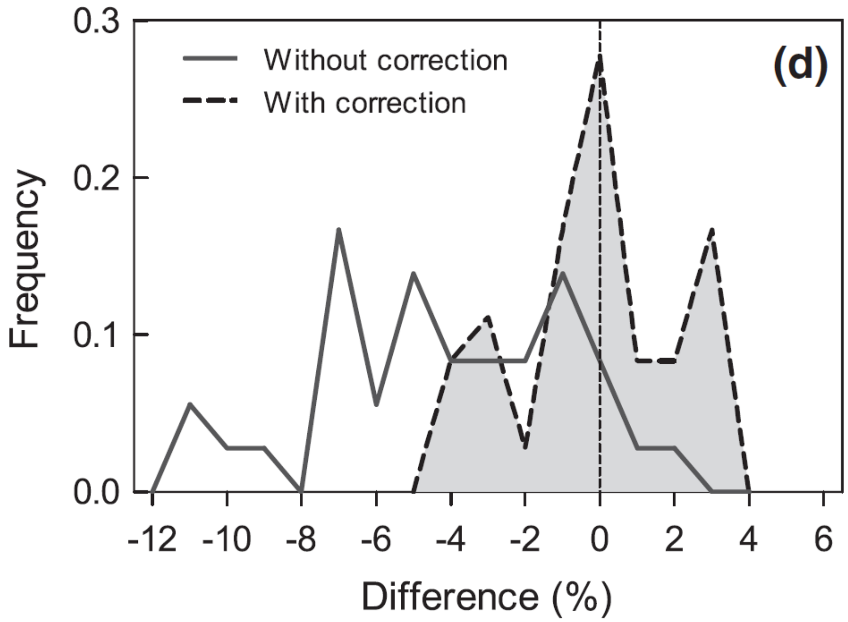


Angular dependency

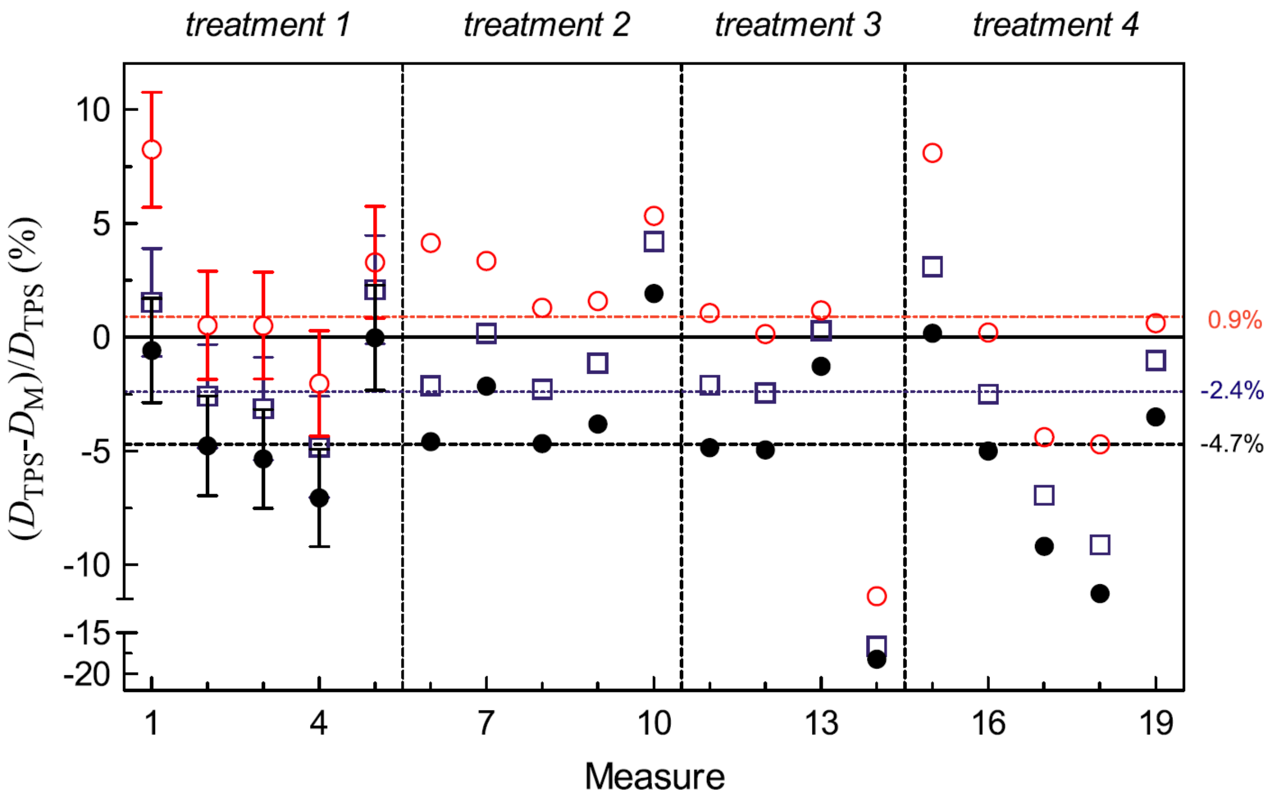


$$f_3(\theta,\phi)^{-1} = b_{(\theta,\phi),0} + b_{\theta,1}\sin(\theta) + b_{\phi,1}\sin(\phi) + b_{\phi,2}\cos(\phi)$$

Angular dependency



Model validation



CONCLUSIONS
(characterization)

- The microMOSFET detectors analyzed present considerable dependencies.
- These dependencies can be corrected using the proposed models, improving the accuracy of the measurements.

IMPLEMENTATION IN CLINICAL PRACTICE

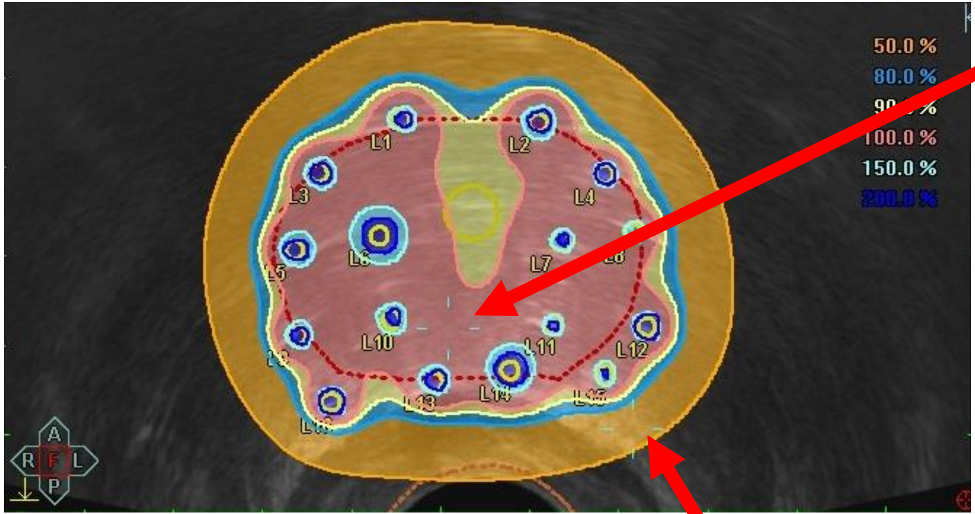
Procedure for the case of real-time prostate implants of HDR:

- Common procedure until needle insertion.
- An additional needle is added for each detector.
- Dosimetry calculation with TPS.
- The point of measurement in the TPS is indicated by ultrasound imaging.
- Treatment is administered at the same time as measurements are performed.
- A file is extracted that records all the dosimetry information of the measurement points and the correction model is applied.

microMOSFET positioning

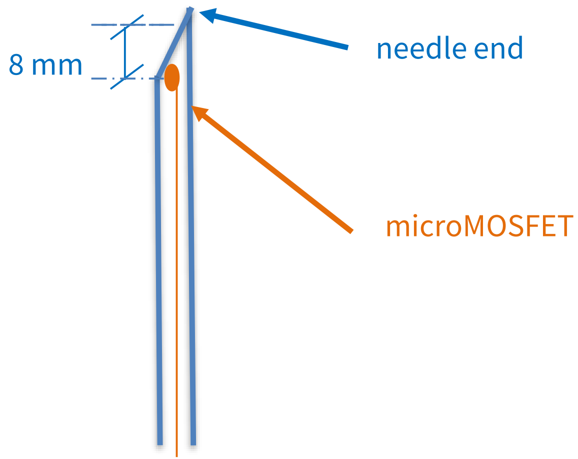
TPS image of a real patient.

mocroMOSFET 1 location



mocroMOSFET 2 location

Needle



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