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Assessing Implant Safety and RF Heating in an Elekta Unity

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Introduction

- Magnetic Resonance-Guided Adaptive Radiation Therapy (MRgART) has grown in clinical use with the production of Magnetic Resonance Imaging - Linear Accelerators (MR-Linac) such as the Elekta Unity.

- **Because many Elekta Unity patients are elderly, implanted devices are highly prevalent**, imposing a unique RF safety environment compared to conventional MRI.
  - At Mary Bird Perkins Cancer Center, 75.5% of all Elekta Unity patients (Oct 2024 – May 2026) presented with an implanted medical device
  - 4.9% of all patients presented **with hip prostheses, which is in or adjacent to the treatment Field-of-View (FOV) for prostate radiation therapy** (68% of all patients)

- Metallic implants produce localized increases in Specific Absorption Rate (SAR), which drive local tissue heating. The International Electrotechnical Commission (IEC) sets SAR and temperature safety limits[1].

- **The MR scanner integrated in the Elekta Unity uniquely operates in First-Level Controlled Mode,** while traditional MRI scanners operate in Normal Mode. Differences are summarized below

Property	Conventional Scanner	Elekta Unity
Physiological stress in patient	Unlikely	Possible
Whole Body Average SAR (wbSAR) limit	2 W/kg	4 W/kg
Extremity local 10g averaged SAR (SAR_{10g}) limit	20 W/kg	40 W/kg
Local tissue temperature limit	40 °C	40 °C
Use case	Diagnostic scans	Tracking tumor position during radiation therapy

Table 1: Summary of differences between a conventional MRI scanner and an Elekta Unity MR-Linac

- **More tolerant safety limits in conjunction with a high prevalence of implanted devices underscore a clinical need to assess implanted device heating**.

Methods

- Electromagnetic and thermal simulations were performed using a Finite-Difference Time-Domain solver (Sim4Life[2]).

- The "Duke" virtual phantom model (IT'IS database[3]) was used. An open-source hip prosthesis was virtually implanted in Duke. Voids were filled with water.

- A **15-minute MRI exam was simulated at 1.5T** with a coil design approximating a Marlin 1.5T present in the Elekta Unity
  - **Perfusion was modeled using the Penne's Bioheat Equation**
  - 6 Measurement points were captured proximal to the apex of the prostate, and along the length of the hip prosthesis

- **Prior to thermal simulation, results were normalized to 4 W/kg wbSAR**

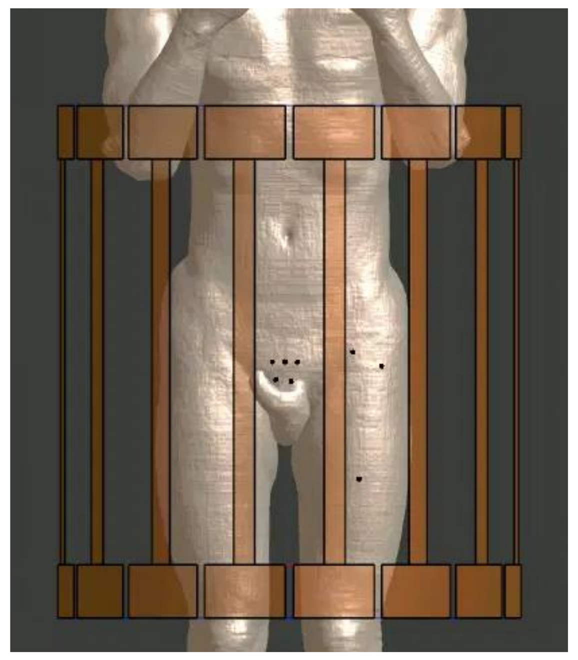

Figure 1: IT'IS Duke model and birdcage coil. The black dots are points of measurement in Figure 2.

Parameter	Value
Tissue T_0	37 °C
Air Temperature	25 °C
RF Pulse Frequency	64 MHz
Pulse Bandwidth	2kHz
MRI Exam Length	900s
Coil Length	700mm
Coil Diameter	700mm
Grid Resolution	2mm x 2mm x 2mm
Implant Material (RF)	Perfect Electrical Conductor
Implant Material (Thermal)	Cobalt-Chromium-Molybdenum

Table 2: Parameters used in FDTD and Thermal Simulations

Results

- 10g mass averaged SAR (SAR_{10g}) was highest at the distal tip of the hip prosthesis (Figure 4)
  - A secondary local maximum in SAR_{10g} was observed at the femoral head.

- High surface SAR within a small tissue mass adjacent to the implant produced SAR averaging artifacts circumferentially around the prosthesis (Figure 4)
  - 1g mass averaging smoothed these artifacts, but SAR_{1g} is not clinically used.

- The right side of Duke ΔSAR_{10g} stayed within $\pm$0.1 W/kg, with a corresponding -0.1°C < ΔT < 0.03°C, indicating the prosthesis had little effect

- Within the prostate, the left lateral surface had the greatest implant driven heating, reaching ΔT of 0.075°C. Adjacent regions had ΔT of ~0.1 °C (Figure 6).

- Under baseline operating conditions (un-normalized) ΔT reached 0.64°C at the distal end of the hip prosthesis; normalized to 4 W/kg wbSAR, ΔT reached 6.4 °C
  - This represents the largest ΔT observed (Figure 3, Table 3)

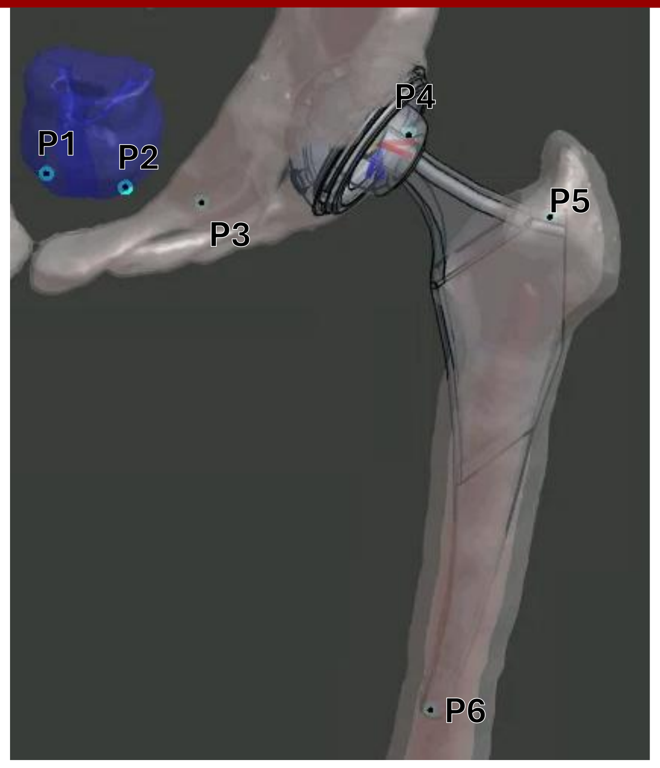

Figure 2: Points of measurement labeled 1– 6. The prostate is marked in blue

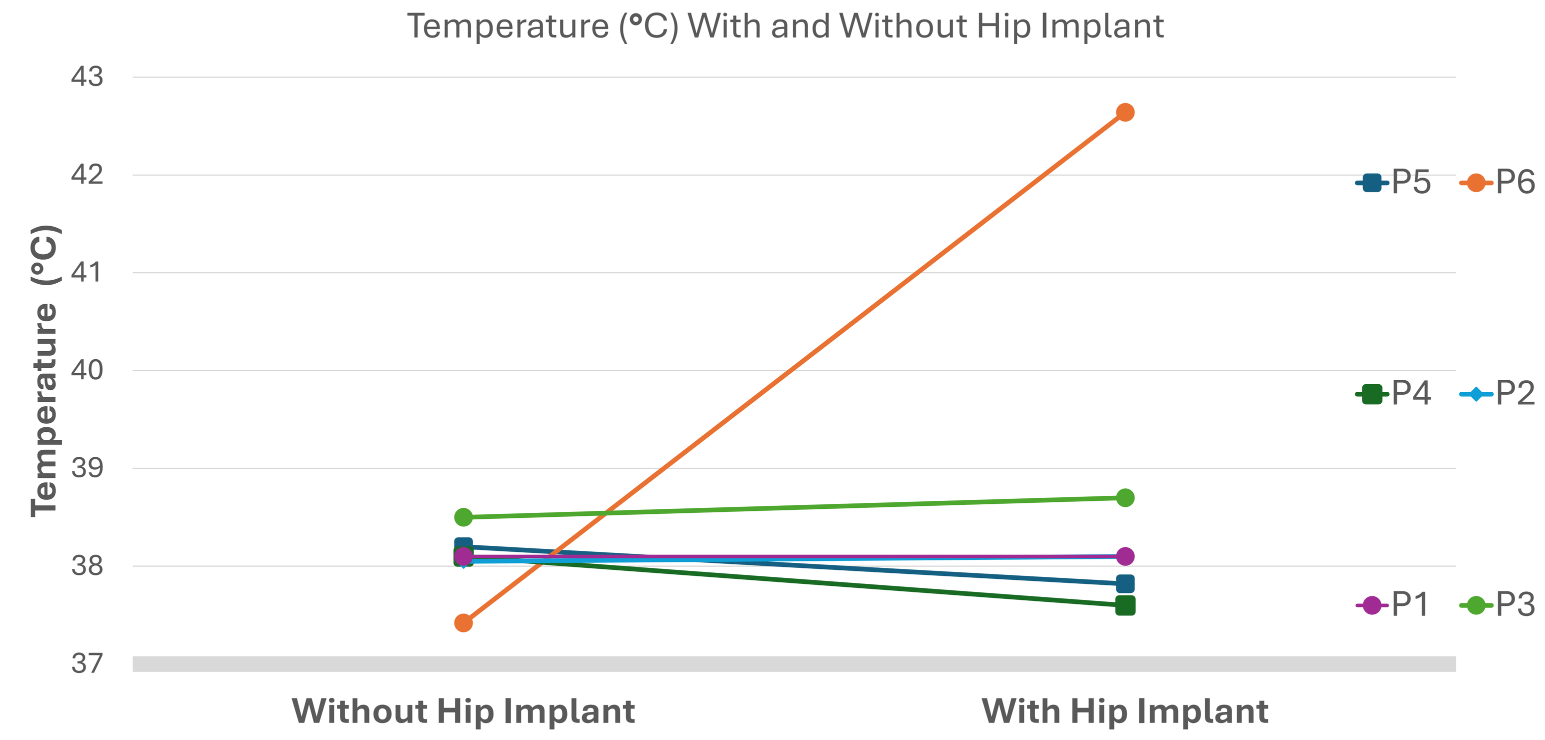

Figure 3: Temperature changes with the hip implant present for points 1-6 following a 15-minute RF exam at 1.5T

Location	ΔT (°C)
Right Side of Duke	0.03
Distal Tip of Prosthesis	6.4
Urethra	0.213
Left Lateral Prostate Surface	0.075
Left Bladder Surface	-0.194
Femoral head	2.2
Left Flank	-1.5

Table 3 : Summary of ΔT for various anatomical points

- Thermal differences at the superior edge of the FOV were minimal (<.1 °C)

- The implant head had high local heating, likely from the sharp material changes between the implant mount, cup, and socket, and its rigid geometry.

- Cold spots were lateral to the hip prosthesis (Figure 4,5).
  - SAR_{10g} decreased ~10W/kg with the hip implant.
  - Accompanied by a ~1.5°C temperature drop.
  - Likely due to local destructive interference from the highly conductive metal prosthesis.

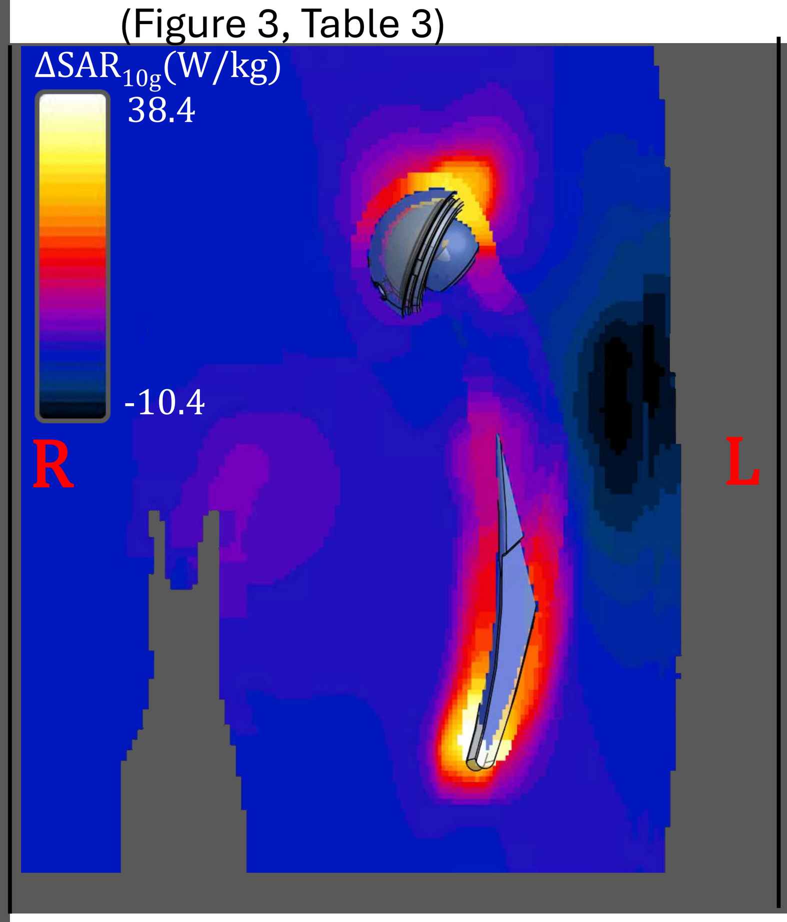

Figure 4: Coronal view of normalized ΔSAR_{10g} in presence of hip prosthesis compared to without the prosthesis.

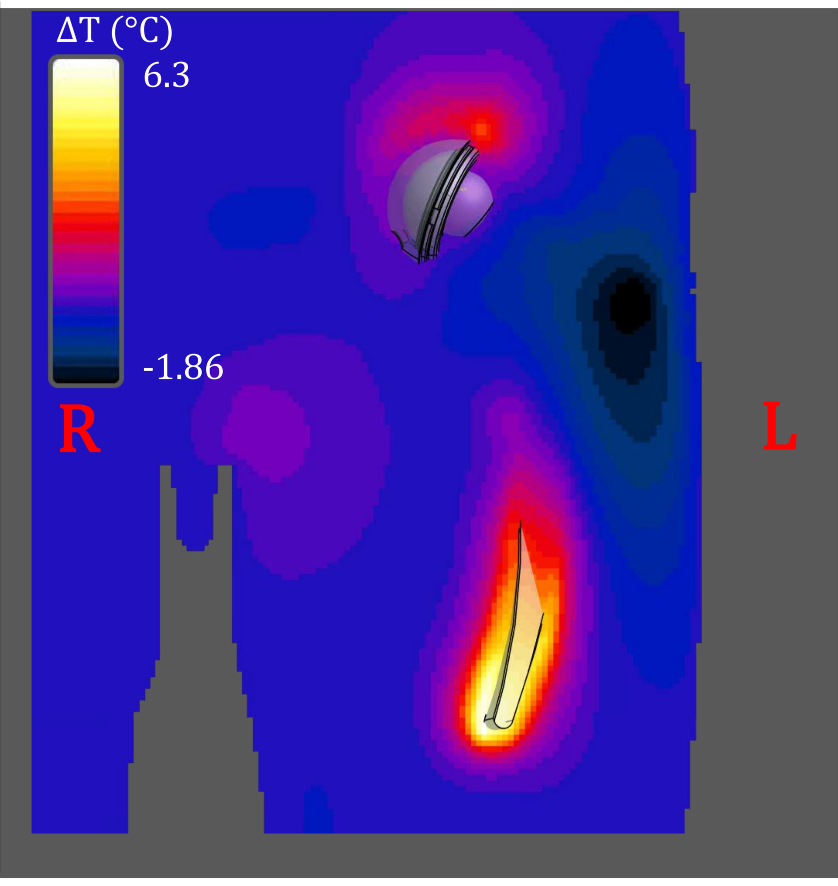

Figure 5: Coronal view of normalized ΔT with hip prosthesis compared to without the prosthesis

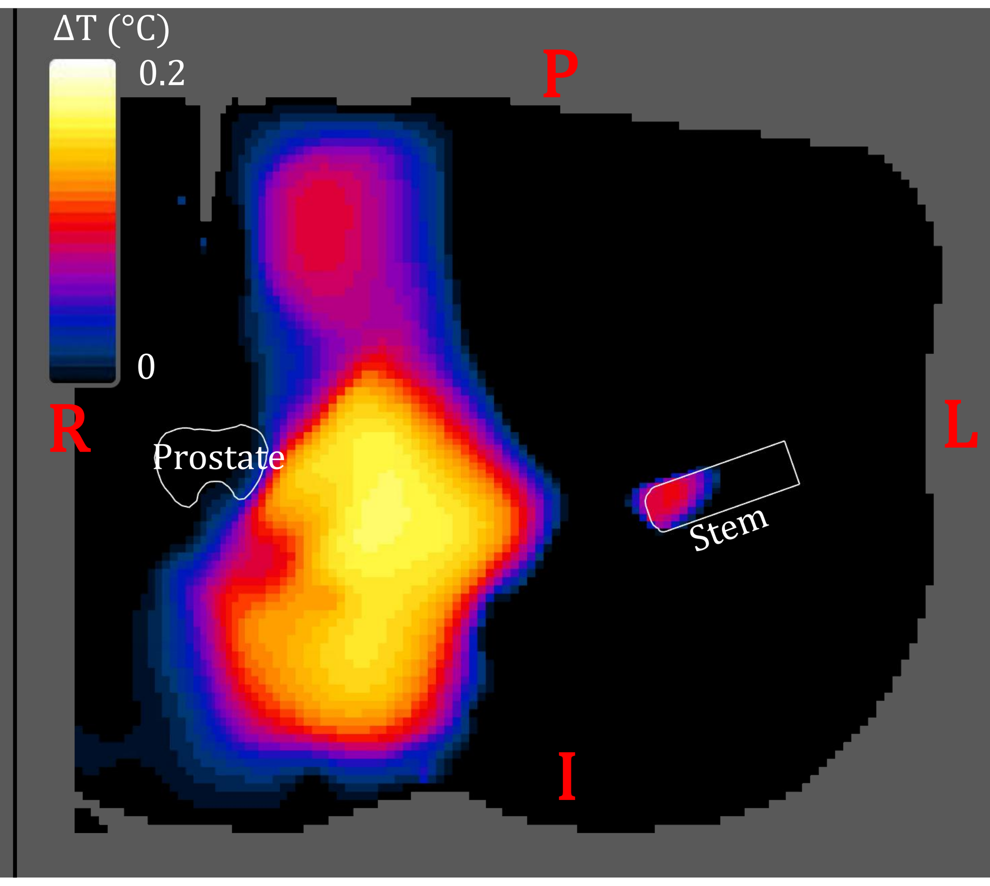

Figure 6: Axial view of ΔT with hip prosthesis compared to without the prosthesis. The prostate and prosthesis stem are outlined.

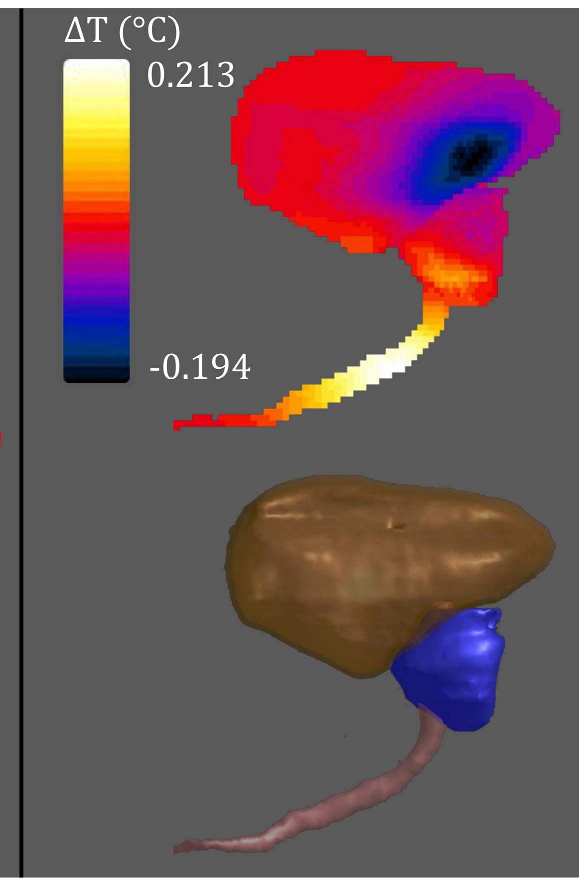

Figure 7: Sagittal view of prostate, bladder, and urethra and corresponding ΔT map

Conclusions & Discussion

- The sharp local SAR_{10g} and temperature spike at the distal end of the prosthesis exceeds RF heating safety limits (>40 W/kg, >40°C) when including baseline SAR_{10g} and initial body temperature.

- Tissue inferior to the prostate was heated, including the prostate surface and the urethra. While these changes are small in magnitude, these regions are within the prostate radiation treatment site, **warranting further investigation into implant driven heating near the prostate and adjacent organs during radiation therapy.**

- High SAR sequences, such as Turbo Spin Echo, cine imaging, and diffusion-weighted imaging may approach the wbSAR limits. Future work should explicitly model these sequences to assess heating.

- **Overall, further evaluation of implanted device heating within cancer patients under clinical conditions is justified**

Future Work

Simplify tissue requirements ⇨ Correct for limited FOV ⇨ Simulate Clinical Scans

Acknowledgements & Sources

1. International Electrotechnical Commission. IEC 60601-2-33:2010: Medical Electrical Equipment - Part 2-33: Particular Requirements for the Basic Safety and Essential Performance of Magnetic Resonance Equipment for Medical Diagnosis. 3rd ed. with amendments. International Electrotechnical Commission; 2015
2. Sim4Life, ZMT Zurich Medtech AG
3. Baumgartner C, Hasgall PA, Di Gennaro F, Neufeld E, Lloyd B, Gosselin MC, Payne D, Klingenböck A, Kuster N, "IT'IS Database for thermal and electromagnetic parameters of biological tissues," Version 5.0, August 21, 2025, DOI: 10.13099/VIP21000-05-0. itis.swiss/database

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Location	ΔT (°C)
Right Side	0
Distal Tip of Prosthesis	0.05
Urethra	0.2
Left Lateral Prostate Surface	-0.5
Left Bladder Surface	0
Femoral head	2.2
Left Flank	-1.5