Enhancing Force Readiness: Restoring MRI Access for Warfighters with Spinal Cord Stimulators

A regulatory-grade, physics-based low-field MRI safety characterization, validated per ISO/TS 10974

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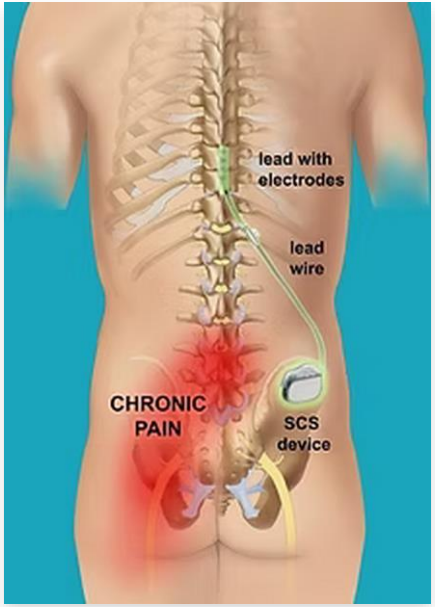
- Laleh Golestani Rad, PhD has no conflict to report

The patient we turn away

- **18.0%** of the force sought care for a spine injury in FY21, its leading musculoskeletal burden.[1]
- For the chronic, refractory cases, a **spinal cord stimulator** is a standard therapy.[2]
- **82-84%** of SCS patients then need an MRI within 5 years; **59-74%** a non-spine MRI within 10 years.[3]

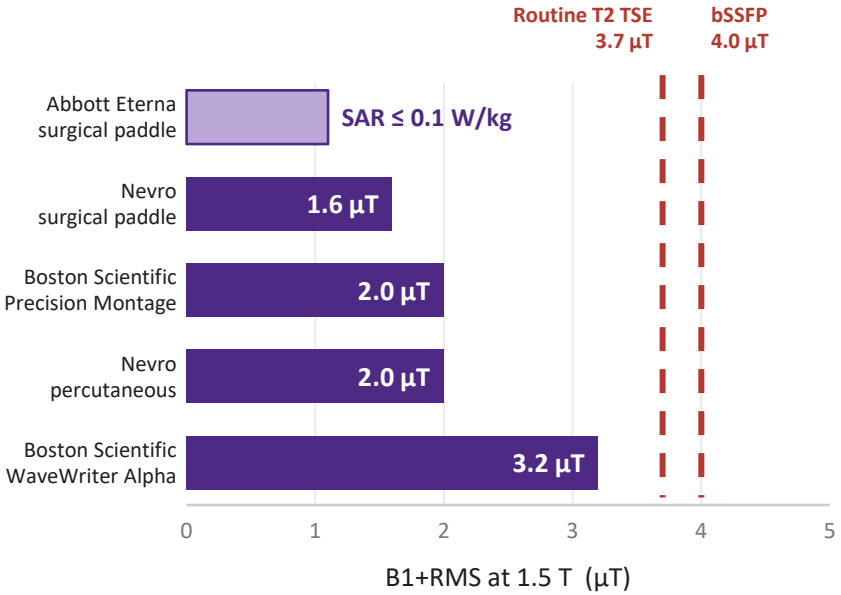


A warfighter with chronic low-back pain, and the spinal cord stimulator implanted to control it.

1. Yuan X, et al. Musculoskeletal Spine Injuries in U.S. Active-Duty Service Members. Mil Med 2024;189(Suppl 4):45-55.
2. Kumar K, et al. SCS vs. conventional medical management for neuropathic pain (PROCESS RCT). Pain 2007;132(1-2):179-188.
3. Desai MJ, et al. The Rate of MRI in Patients With Spinal Cord Stimulation. Spine (Phila Pa 1976) 2015.

“MR Conditional” does not mean scannable

- **A $4 billion market**, and nearly every maker now sells an MR Conditional SCS.
- But **MR Conditional** means scannable only while RF power stays under the device's B1+RMS limit.
- The routine scans these patients need **exceed most device caps**, and the limit bites hardest right over the implant.

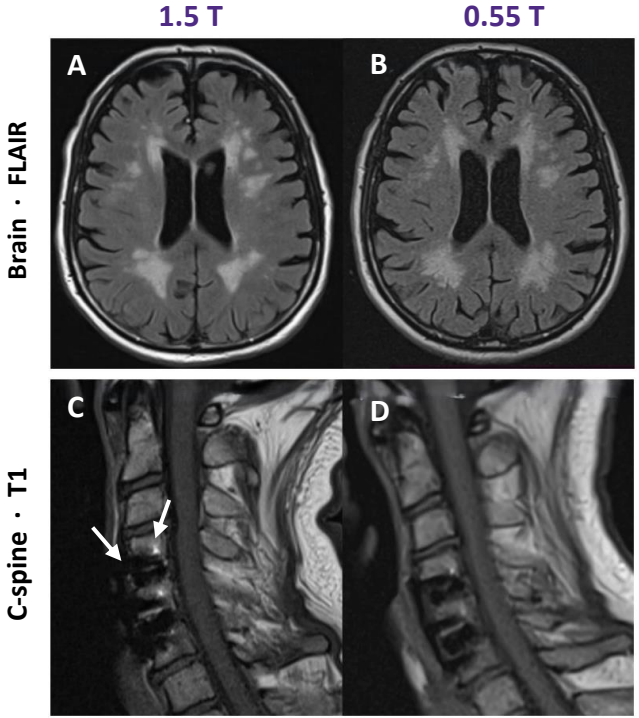


Abbott's bar is derived from its whole-body SAR limit (≤ 0.1 W/kg), converted to B1+RMS via SAR proportional to B1+ squared (@ 1.5 T, 4.8 µT ≈ 2 W/kg).

Could low field be the answer?

- Low field is where MRI began. In 2021 the FDA cleared the first 0.55T system.
- Its images match 1.5T diagnostically in brain, spine, and joints, with **less metal artifact**.
- **Force and torque scale with the field squared**, roughly sevenfold lower at 0.55T.
- Without a conductor, SAR scales with **frequency squared**, so low field means less RF for a given B1+. The catch is the conductor.

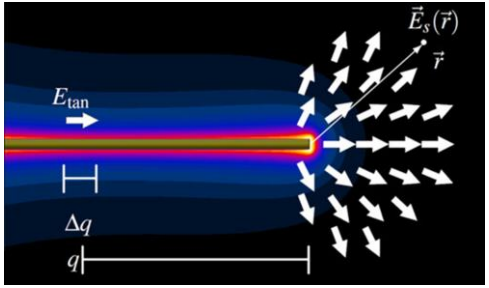
$$\mathbf{SAR} = \frac{\sigma A^2 \omega^2 B_1^2 D^2}{\rho}$$



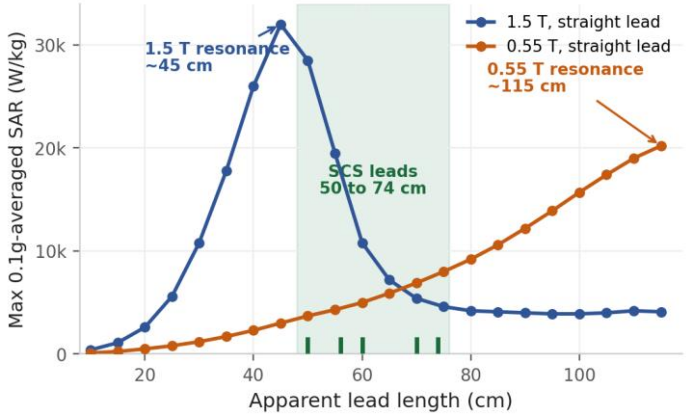
Courtesy of Rusche et al. 2022

It's resonance, not just less RF

- A lead acts as an **antenna**: the tangential RF electric field couples along it and drives currents that amplify RF energy the **tip**, where tissue heats.
- The heating is a **resonance**, peaking when the lead nears half the RF wavelength: about **45 cm at 1.5T**, about **115 cm at 0.55T**.
- SCS leads run **50 to 74 cm**. Across that range 0.55T stays in a **low-heating valley**, while 1.5T runs near its resonance for the shorter ones.



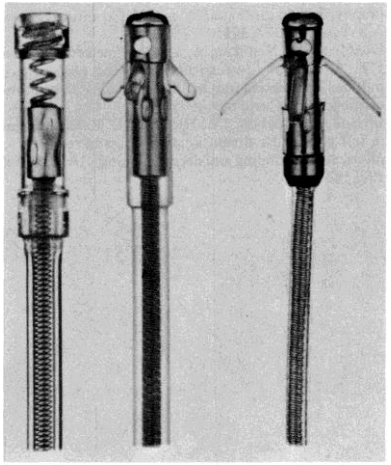
Courtesy of Winter et al., J Magn Reson Imaging 2021



Data: Sanpitak P, et al. Low-field MRI's Spark on Implant Safety: A Closer Look at Radiofrequency Heating. IEEE EMBC 2023. doi:10.1109/EMBC40787.2023.10340861.

Safety you can't see

THE PROBLEM

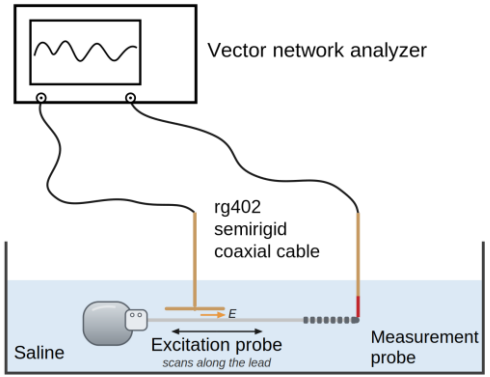


Conductor coiled as a helix.
Perrins et al., Br Heart J 1981.

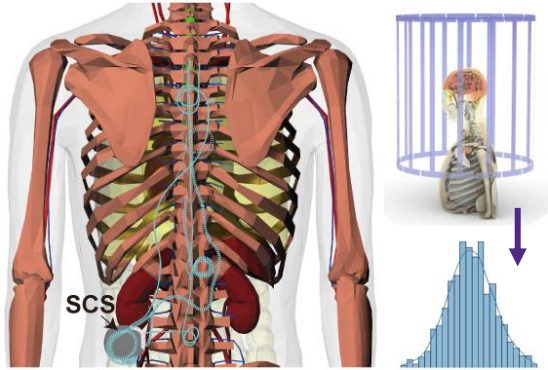
- Conductor is a **tight helix**
- **Electrical length ≫ apparent**
- So **RF risk can't be seen**

THE FDA-RECOMMENDED TEST

1 Measure the response



2 Predict in-vivo ΔT



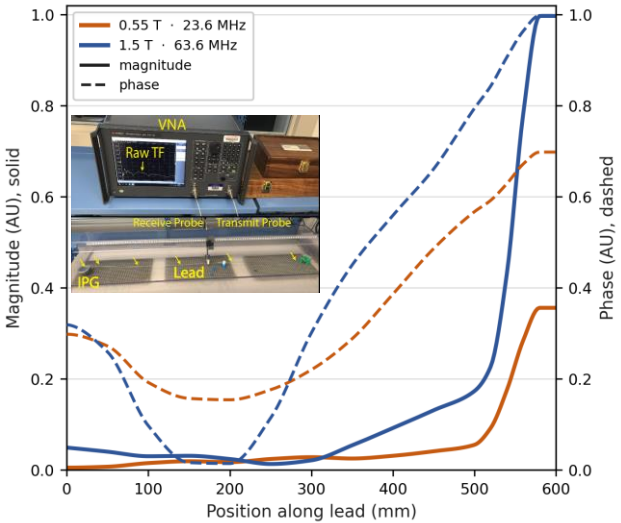
$$\Delta T = C \cdot \left| \int_0^L S(\ell)\, E_{\tan}(\ell)\, d\ell \right|^2$$

S(l) from the measurement E_{tan} from the simulation **C** calibrated experimentally

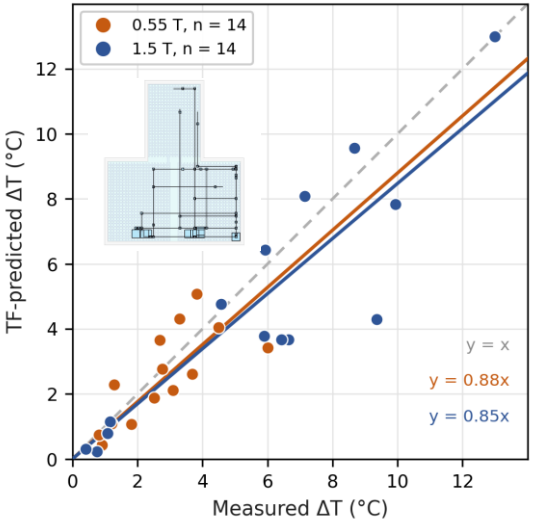
ISO/TS 10974:2018, Assessment of the safety of magnetic resonance imaging for patients with an active implantable medical device. 2nd ed. Geneva: International Organization for Standardization; 2018. (Tier 3 transfer function method, Clause 8.)

The lead's RF fingerprint, measured and validated

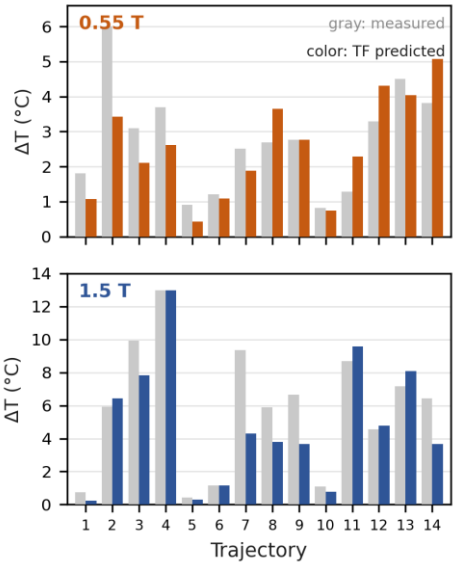
MEASURED TRANSFER FUNCTION



PREDICTED VS MEASURED ΔT



IN VITRO TRAJECTORIES



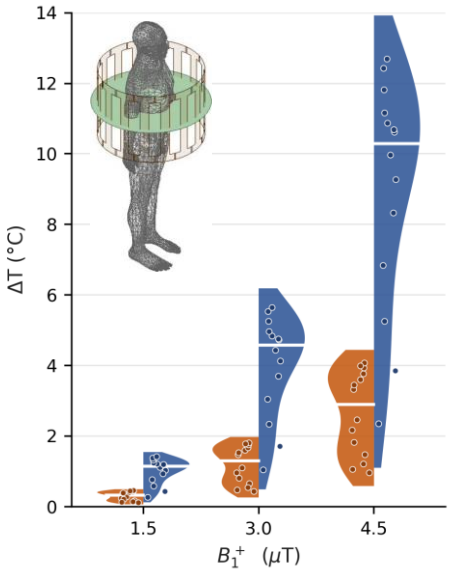
IPG + 60 cm lead · VNA S21 at 1 cm steps · 23.6 / 63.6 MHz

14 orthogonal trajectories per field · high-SAR TSE, B1+ 4.5 µT · Aera 1.5 T / Free.Max 0.55 T · ISO/TS 10974 Tier 3

Heating falls three to four-fold at 0.55 T, but does not vanish

■ 0.55 T (23.6 MHz) ■ 1.5 T (63.6 MHz) · 14 in-vivo trajectories per field, per landmark · dots = individual paths

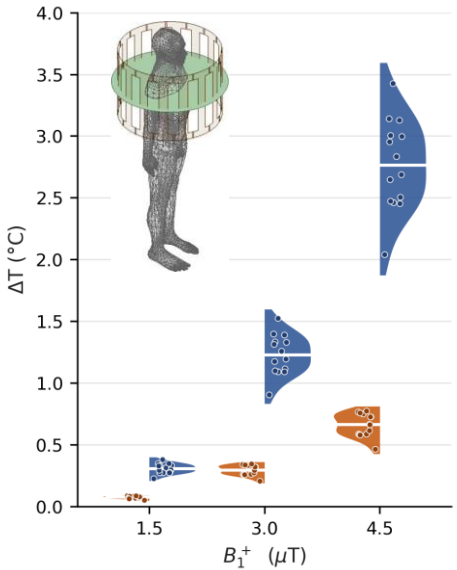
ABDOMEN



12.7 → 4.1 °C

peak ΔT at 4.5 μT · 3.1× lower

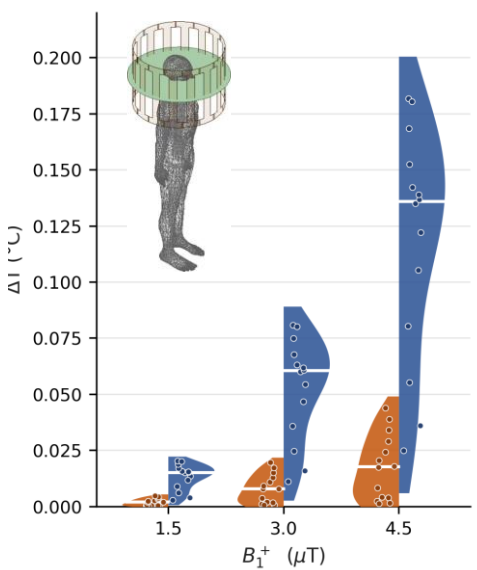
CHEST



3.4 → 0.8 °C

peak ΔT at 4.5 μT · 4.4× lower

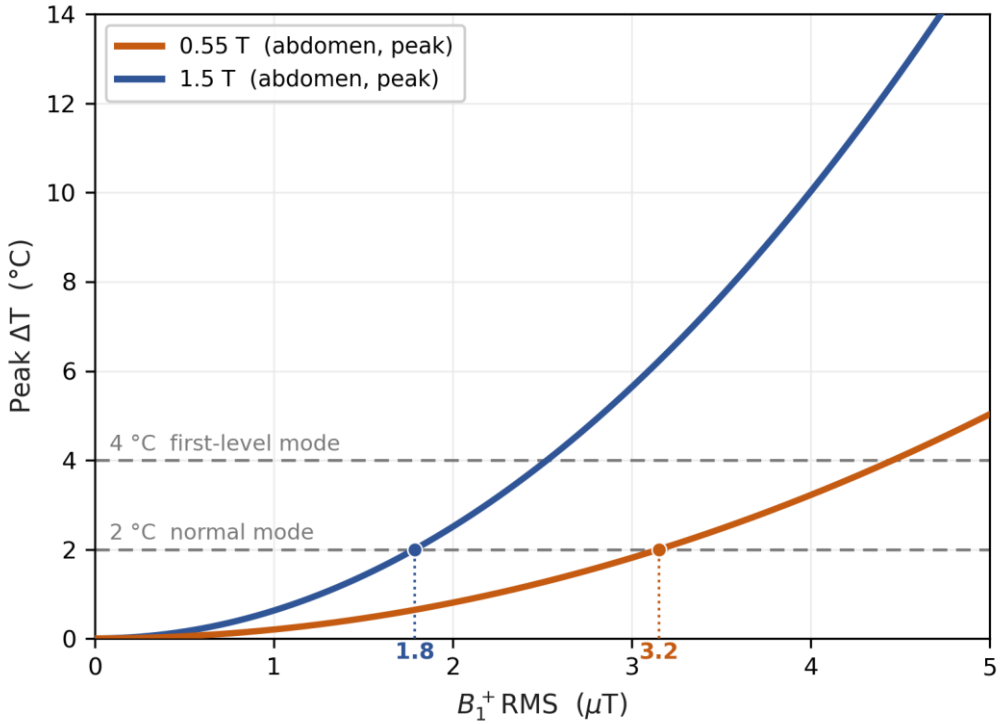
HEAD



under 0.2 °C

negligible at both fields

What it means for scanning: 0.55 T widens the usable window



Abdomen, the binding landmark: peak ΔT vs RF drive, with normal-mode (2 °C) and first-level (4 °C) thermal references

READING BY LANDMARK

Head: unrestricted

Under 0.2 °C at both fields. No RF constraint.

Chest: cleared at 0.55 T

Stays under 2 °C across the clinical range. At 1.5 T, capped near 3.4 μT.

Abdomen: now manageable

1.5 T reaches 2 °C by 1.8 μT. 0.55 T holds to 3.2 μT, roughly 1.8× more RF headroom, and stays under 4 °C to 4.5 μT.

Bottom line: 0.55 T turns a contraindicated abdominal scan into a protocol-managed one and removes the constraint entirely for head and chest.

From this proof of concept to the guidance the field needs

Today's results are the preliminary data. Our goal is to scale them four ways.

01 one device → **the full marketed landscape**

Five-plus manufacturers, dozens of MR Conditional systems, each with its own RF fingerprint.

02 14 trajectories → **50+ for statistical power**

Realistic paths across body sizes and landmarks, for percentile-based operating limits.

03 one 60 cm lead → **the 30 to 90 cm range, and full systems**

Heating is a length-driven resonance; full generator-plus-lead can be worse at low field.

04 prediction → **deployable protocol**

B1+RMS look-up tables and scanning guidance for MTFs and the VA, toward 0.55 T labeling.

Acknowledgments

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