Appendix 1 Methods

Phantom preparation

A phantom was constructed to monitor temperature distributions, composed of agar (0.5 mM), NaCl (171 mM), and $CuSO_4$ (6.27 mM) to emulate the electrical properties of human tissue (8,21,22). These materials were placed in a plastic container and diluted with a hot solution of ultrapure tertiary sterilized purified water (JOYLIFE, Republic of Korea). A lumbar-related metal implant (Lumbar Screw Xia titanium monoaxial 6.5×50 mm; Michigan, USA) was secured at the phantom's center, cooled to room temperature, and maintained within the magnetic resonance imaging room for 24 h to reach temperature equilibrium (8).

Bias field correction

A bias field correction (25) was applied to all magnitude images acquired at 2°, 10°, and 20° to minimize residual low-frequency intensity inhomogeneity, despite the application of transmit radiofrequency magnetic field (B1+) shimming (TrueForm) during acquisition. This inhomogeneity is known to arise from various sources, including B0 inhomogeneity, residual B1+ field non-uniformities, and coil sensitivity profiles.

These factors can affect signal uniformity and confound voxel-wise T1 estimation, especially in quantitative imaging. The correction process estimated and compensated for the multiplicative bias field across the imaging volume, thereby improving the stability and accuracy of T1 mapping.

Proton resonance frequency shift (PRFS) temperature calculation

The PRFS temperature calculation is based on the following equation:

$$\Delta T_{PRFS} = \sum_{i=2}^{n} \frac{(\varphi_i - \varphi_{i-1}) - \Delta\varphi_{f,i}}{\alpha \cdot \gamma B_o \cdot \Delta TE} \quad [1]$$

where n is the number of scans performed during heating, φ is the phase image with delta-echo time (TE), $\Delta\varphi_f$ is the field drift map, α is the PRFS coefficient (–0.01 ppm/°C), γ is the gyromagnetic ratio, B_o is the main magnetic strength, and ΔTE is the delta-TE (1.23 ms). The PRFS process utilizes delta-TE phase images as a complex sum of dual echoes. The background field drift $\Delta\varphi_{f,i}$ during heating was estimated by tracking the temporal phase changes in the four oil phantoms. The drift maps were generated using delta-TE phase images, following the methodology described in a previous study (8).

Correlation analysis between temperature and T1/phase values

To evaluate the relationship between temperature and imaging biomarkers, correlation analyses were performed in MATLAB (MathWorks, Natick, MA) using data acquired from phantom experiments.

T1 correlation

As the temperature increases, the T1 values concomitantly increase as well (10). To investigate this relationship, a correlation analysis was performed on MATLAB between temperature and T1 values. This analysis resulted in a strong positive correlation (r=0.84, P<0.01).

PRFS phase correlation

Although phase values are generally expected to increase with rising temperatures (10,12), the phantom data revealed a

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negative correlation between phase values and temperature ($r=-0.86$, $P<0.01$). This inverse correlation is likely due to susceptibility-induced off-resonance effects caused by the presence of metallic implants, which can overshadow temperature-dependent frequency shifts.

Table S1 MRI scan parameters

Parameter	Value
Repetition time (TR)	4.5 ms
Echo time (TE)	1.23/2.46 ms
Flip angle (FA)	2°, 10°, 20°
Field of view (FOV)	320×320×40 mm^3
Matrix size	128×128
Slice thickness	5 mm
Bandwidth	1,080 Hz/pixel
Number of averages	1
GRAPPA factor	2
Slice oversampling	25%
B1 shim	TrueForm
Acquisition time	12 s

MRI, magnetic resonance imaging.

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