A whole-body RF dosimeter for independent SAR measurement in MR scanners

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Target audience: Medical Physicists, MR Service & RF Engineers, Researchers testing MR safety of devices, leads, and sequences.
PURPOSE: Correct determination of patient whole-body average SAR during MRI scans is essential for assessing MR safety [1]. We have developed an RF dosimeter that can measure power deposition independent of the MR scanner. The dosimeter has an RF transducer with two tuned, orthogonal, lossy loops that mimics the loading by an average human subject, and a spherical phantom for the scanner to set the RF field, B1. However, currents induced on the transducer loops by the scanner can change the net B1, causing the scanner to incorrectly set the RF power output required to produce a prescribed flip angle. By a particular loop tuning, we make the final, resultant B1 the same as the original B1, thus ensuring that our RF transducer produces minimal B_1 disturbance. Power calibration curves obtained for eight 3T scanners including Philips, GE and Siemens models show that the dosimeter is independent of scanner or model operating at the same MR frequency. The results can be used to estimate whole-body SAR.
METHODS: The RF transducer comprises two orthogonal copper strip rectangular loops (70 cm x 50 cm) fixed on a polycarbonate frame (Fig 1a). The loops' loading and tuning were adjusted by a series of distributed capacitors and resistors. A lossless 10 cm diameter mineral oil ball was positioned at the transducer center to give an MR signal for the scanner's B1 calibration. Two 3 T RF transducers were constructed: one that operated at 127.8 MHz for Philips and GE scanners, and one at 123.8 MHz for Siemens.

The effect of currents induced in the transducer loops and their resulting contribution to B1 was analyzed analytically. An algebraic solution was found for the reactance X in each loop that keeps the net B1 equal to the applied B1:

$$X = \left(2\omega\mu_0/\pi\right)\sqrt{a^2+b^2}\ , \tag{1}$$

where a and b are the length and width of the rectangular loops. The important property of this solution is that X is independent of the resistance R in the loop. Thus once X is determined and established to maintain the desired net B1, the loop resistance R can be varied to achieve the desired loading without changing X which would otherwise involve retuning the loop.

Experiments were performed with the RF transducers in the bore of 3T scanners (3 Philips, 3 GE and 2 Siemens systems; various models). Forward and reflected powers were measured at the inputs of the body coil using a high dynamic range multi-channel power monitor [2] to determine deposited power. The power monitor was connected across a 50 Ω series resistor in each loop via directional couplers, attenuators and baluns for protection (Fig 1a) to measure induced currents. The power sampled by the power monitor was $P_{sampled}$. $P_{deposited}$ was varied as a function of scan parameters to obtain calibration curves of $P_{sampled}$ vs. $P_{deposited}$ for each scanner.
RESULTS: Fig. 1b is a calculated contour plot of relative B1 magnitude. The plot shows that when the loop reactance X = 196 Ω, the normalized B1=1, and the net field magnitude (applied + induced) is the same as the applied field, independent of the loop resistance. Experiments performed with a loop reactance X ≈200 Ω, and a Philips Achieva scanner showed that the initial power optimization flip angle varied ~2% from the prescribed flip angle, consistent with this calculation of the reactance needed to minimize B_1 disturbance.

With loop R = 375 Ω, the 127.8 MHz (GE/Philips) transducer had $P_{deposited}$ = 24.4W, equivalent to a "standard" 89 kg human subject with BMI 24. The $P_{deposited}$ vs. $P_{sampled}$ calibration curve obtained from multiple GE and Philips 3 T systems are highly linear, correlated, and can be fit by a single curve (Fig. 1c). The same findings obtain for the 123.8 MHz dosimeter in the Siemens scanners.
CONCLUSION: $P_{deposited}$ derived from $P_{sampled}$ measured on the 3T RF transducers, provides body-coil RF dosimetry independent of the scanner (make or model). The whole body average SAR for the "standard" subject can be calculated from $P_{deposited}$ measured by the dosimeter divided by the subject's weight. As has been shown previously, $P_{deposited}$ is approximately a linear function of BMI [2], and can be used to estimate SAR for different-sized subjects, based on a single dosimeter measurement.

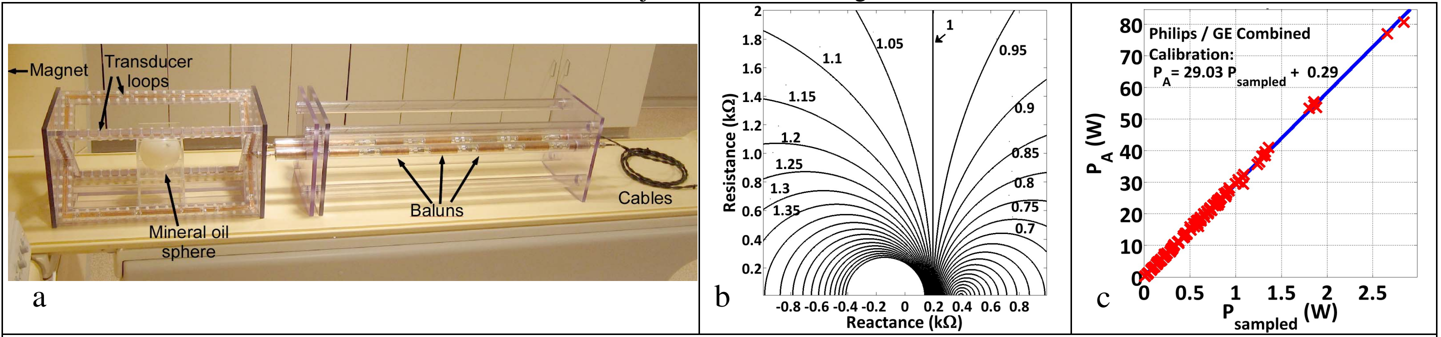

Fig.1. (a): SAR dosimeter assembled; (b): Contour plot of net B1 magnitude as a function of loop reactance X and loop resistance R is independent of R at X=196 Ω; (c): 127.8 MHz dosimeter calibration curve of $P_{deposited}$ vs. $P_{sampled}$. Data are from 6 GE & Philips scanners.

REFERENCES: [1] J P. Stralka, et al. JMRI 2007; 26:1296-1302. [2] AM El-Sharkawy et al. Med Phys 2012;39,2334-2341. *NIH R01 EB007829.*