To Cool or Not to Cool: the Question for Skin Microscopy Receive Coils

J. C. DiCarlo[1], G. C. Scott[1], S. M. Conolly[2], B. S. Hu[3], D. G. Nishimura[1]

[1]Electrical Engineering, Stanford University, Stanford, California, United States, [2]Bioengineering, University of California, Berkeley, Berkeley, California, United States, [3]Cardiology, Palo Alto Medical Foundation, Palo Alto, California, United States

Introduction

Each year in the United States, there are over 10,000 amputations as a result of peripheral vascular disease (PVD). PVD is often first diagnosed by non-healing skin lesions, before cramping symptoms have occurred [1]. Early morphology changes could be seen by biopsy, but wound-healing concerns make it unfeasible. High-frequency ultrasound (US) and optically based techniques are currently limited by the echo-poor nature of skin structures [2] and depth limitations of near infrared light [3].

Magnetic resonance imaging provides skin structure signal over all layers, but requires significant SNR improvement to maintain reasonable 3D imaging time. Others have shown that cooling copper receive coils to 77 K using liquid nitrogen significantly improves SNR for microscopy since coil noise is the dominant loss term [4,5]. In this abstract, we examine the tradeoff of increased SNR from decreased copper resistance at 77 K and B_1 losses due to cryostat-induced liftoff. Specifically, we examine the optimal coil operating configuration at a range of coil sizes for the application of skin microscopy.

Methods

Four Doty copper-wire coils of diameter 10 mm (3-turns,) and 24, 32, and 38-mm (1-turn) were modified for use with a GE 1.5T Excite scanner with CV/i gradients. The coils varied from the minimum size for required tissue sensitivity depth to that above the sample-noise dominance crossover point at 26-mm. A polystyrene cryostat was constructed with a coil-sample spacing of 3 mm. The thickness is smaller than that reported in [4,5] and allows sufficient hold time for sample SNR measurements. SNR was measured over a 5-mm deep ROI in chicken muscle images. Images were acquired in 3 configurations: each coil 1) at 300 K next to the sample, 2) at 300 K with the 3-mm cryostat liftoff, and 3) at 77 K, with the 3-mm cryostat liftoff. Image-measured SNR was compared to simulated predictions averaged over the same sample depth. For each of the coil sizes, SNR vs. depth into the sample x with a liftoff of h (including cryostat, coil thickness/backing) was computed using [6]:

$$SNR(x) \propto \frac{B_1(x+h)}{\sqrt{R_{Sample}T_{Sample} + R_{Coil}T_{Coil}}}$$

R_{Coil} was computed assuming a wire diameter of 1.75 mm (matching the Doty coils) and proximity factor of 3 for the 3-turn 10-mm coil. R_{Sample} was computed as in [6] using a sample conductivity of 0.53 S/m. Skin images were acquired using the 10-mm coil at 300 K, positioned next to the calf of a normal volunteer and a diabetic patient with neuropathy and PVD. A 4x4x1 cm^3 slab of 78-μm in-plane resolution was acquired using a rapid 3D GRE sequence with 31.25-kHz BW in a scan time of ~2 minutes.

Table 1. Predicted vs. image-measured SNR, averaged over a 5-mm depth into the sample. (Normalized to 38-mm coil at 300 K.)

Coil diameter (mm)	10	24	32	38
Predicted SNR, 77 K	5.08	3.04	1.63	1.10
Predicted SNR, 300 K	5.48	2.73	1.48	1
Predicted SNR, 300 K, with 3-mm spacing	2.39	2.53	1.47	1.01
Measured SNR, 77 K	3.3	2.6	1.7	1.1
Measured SNR, 300 K	4.5	2.2	1.4	1.0
Measured SNR, 300 K, with 3-mm spacing	2.6	1.6	1.2	1.1

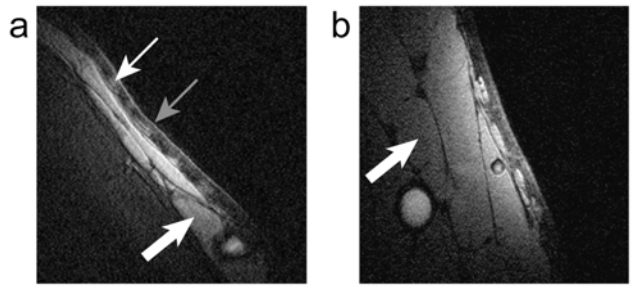

Figure 1. 2x2-cm^2 3D-GRE images using the 10-mm coil at 300 K without cryostat liftoff in a) a normal volunteer, and b) in a diabetic patient with neuropathy and PVD. Scan time was 2:09.

Results

Table 1 shows predicted vs. measured SNR. There was no cooling gain expected over a room-temperature configuration without the cryostat spacing at a coil diameter of 10 mm. Imaging measurements showed no gain in cooling the 10-mm coil. For the 3 larger coil sizes, a gain in cooling was measured as expected. The predicted values also demonstrate the slight SNR increase by a 3-mm cryostat liftoff at the sample-noise dominated coil size of 38 mm. The highest achievable SNR in the skin is with the 10-mm coil positioned next to the skin at room temperature. This configuration was used to acquire the images in Figure 1. Delineation of the epidermis (gray arrow,) papillae (thin white arrow,) and hypodermic fat layer (wide white arrow) are evident in a 3D data set that has been acquired in just over 2 minutes. Differences in epidermal and dermal layer contrast are evident in the diabetic skin.

Conclusion

For skin imaging, there was no cooling benefit with a cryostat thickness of 3 mm or greater. We have demonstrated 78-μm in-plane images acquired with a 10-mm coil at 300 K in just over 2 minutes. The technique shows great promise for morphology imaging of ischemic skin, as well as contrast-based skin perfusion studies.

References

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