Improved RF Safety of Interventional Devices using Cable Traps

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INTRODUCTION

Radio frequency (RF) microcoils built into the distal tips of endovascular catheters enable accurate tip tracking and high resolution, limited field-of-view imaging for MRI-guided endovascular interventions. These microcoils are connected to the external system using one or more coaxial cables. The large RF magnetic fields generated during the transmit cycle induce large currents in the microcoils and coaxial cable shield, resulting in RF heating. The RF heating is most severe in the microcoils. In some cases, temperature rise of up to 55 °C has been reported. A number of methods for suppressing RF heating have been suggested before and include the use of quarter-wave sleeve baluns implemented on triaxial cables [**1**] and transformer-coupled transmission lines [**2**]. One disadvantage of the sleeve balun design is that, while micro-coaxial cables are lossy, comparable thin-triaxial cables are even more so and may result in unacceptable signal loss. Furthermore, micro-triaxial cables are not commonly available and have to be custom manufactured. Transformer-coupled transmission lines successfully suppress the large common-mode currents induced by the transmit B_1 field. However, signal loss due to inefficient coupling between transformers may be acceptable for active tip tracking applications but is unacceptable for catheter-based imaging. Recently, our group has introduced the multi-mode RF coil that combines the functionalities of tip tracking and imaging into a single device [**3**]. In this design, we proposed the use of a coaxial-trap balun to suppress the formation of current and voltage standing waves on the coaxial cable shield. In this work, we investigate the effectiveness of the coaxial-trap baluns in suppressing RF heating. The objective of this work is 1) to measure the dependence of the severity of the device tip heating on the resonant length of the coaxial cable and 2) to determine the effectiveness of the cable-trap baluns in suppressing RF heating.

MATERIALS AND METHODS

Two tightly-wound solenoidal coils (15 turns of 36 AWG magnet wire) were implemented at the distal end of 6 F double lumen catheters (Boston Scientific). The coils were matched and tuned to the 50Ω characteristic impedance of a microcoaxial cable (42 AWG center conductor, Alpha Wire) at 64 MHz. On one of the catheters (catheter A), a straight length of coaxial cable was used to connect the coil to a connector located at the proximal end of the catheter. On the other (catheter B), two coaxial cable-trap baluns were formed, each by implementing 70 tightly-wound turns of the coaxial cable around the catheter. The shield impedance of each balun was measured to be 510Ω. One of the baluns was placed close to the coil terminals while the other was placed toward the proximal end of the catheter. Note that the baluns were not resonant at 64 MHz, but simply presented a high inductive reactance to currents induced on the coaxial cable shield.

Catheters A and B were placed in cylindrical phantoms (length: 45 cm, ID: 4 cm) filled with 0.9% physiologic saline. As indicated in figure 1, the phantoms were placed parallel to the z-axis and 15 cm off-center in the bore of a 1.5 T MRI scanner (GE Signa). Fiber optic temperature probes (Neoptix) were inserted into the main lumen at the distal tip of catheters A and B to monitor temperature rise. Open ended extension coaxial cables that were cut to equal lengths (136 cm) and connected to the micro coaxial cables of catheters A and B at their proximal ends served to extend the total lengths of the coaxial cables beyond their respective resonant lengths.

During a 2 minute scan using a 2D multi-slice TrueFISP sequence (TR/TE=4/1.3 ms, Flip=90°, FOV=48 cm, slice thickness= 5 mm), the phantoms were imaged and the maximum temperature rise was recorded. The temperature measurement experiments were repeated 24 times after shortening the length of the extension cables by 5.3 cm each time. The maximum temperature rise corresponding to the various extension cable lengths were plotted for both catheters A and B.

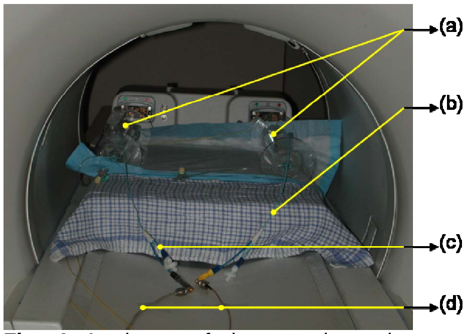

Fig. 1 A picture of the experimental setup showing (a) the saline phantoms, (b) catheter A, (c) catheter B and (d) the equal length extension cables.

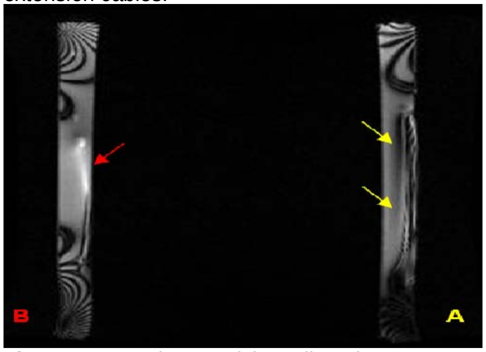

Fig. 2 An SSFP image of the saline phantoms. The severe inhomogeneity due to the catheter A is indicated by the yellow arrows. The orange arrow indicates reduced inhomogeneity due to baluns on catheter B.

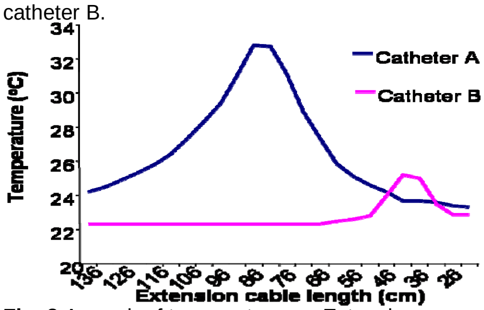

Fig. 3 A graph of temperature vs. Extension cable length for both catheters A and B shows 1) large rise in temperature at resonant length of cable and 2) effectiveness of coaxial baluns in restricting temperature rise.

RESULTS AND DISCUSSION

A sample image of the saline phantoms containing catheters A and B for the worst case SSFP flip angle of 90° is shown in figure 2. The severe inhomogeneity in the vicinity of the straight coaxial cable in catheter A, as indicated by the yellow arrows, is caused by the currents induced on the coaxial cable shield. The inhomogeneity is significantly reduced if not completely eliminated due to the presence of baluns in catheter B. Comparitive plots (figure 3) of the maximum temperature rise at the distal tip of catheters A and B show a maximum temperature rise of 10 °C for catheter A and less than 3 °C for catheter B. The plots also show that RF heating is sensitive to the resonant length of the coaxial cable. For non-resonant lengths, the temperature rise of less than 1 °C is insignificant even for a straight length of coaxial cable.

CONCLUSIONS

Our results clearly demonstrate the potential utility of coaxial cable-trap baluns in suppressing RF heating to acceptable levels. Another major advantage is the design simplicity that results in ease of implementation. An alternative configuration is to place more baluns with fewer turns to minimize the impact on the catheter mechanical properties while simultaneously presenting high impedance to currents induced on the micro coaxial cable shield.

REFERENCES

1. Ladd *et al*, MRM, 43, 615, 2000. **2.** Weiss *et al*, MRM, 54, 182, 2005. **3.** Kurpad *et al*, ISMRM 2007.

ACKNOWLEDGMENTS

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