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Characterization and flip angle calibration of ^{13}C surface coils for hyperpolarization studies

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Synopsis

The aim of the present work is to address the challenge of optimal flip angle calibration of ^{13}C surface coils in hyperpolarization studies. To this end, we characterize the spatial profile of the flip angle and demonstrate that it allows for a simple calibration improving the signal-to-noise ratio for hyperpolarized ^{13}C magnetic resonance spectroscopic imaging.

Introduction

For hyperpolarized ^{13}C magnetic resonance spectroscopic imaging (^{13}C-MRSI), flip angle (FA) calibration is challenged. Therefore, a ^{13}C enriched phantom placed outside the imaged object is commonly used as reference. This does, however, give potential errors in case of RF transmit field (B_1) inhomogeneities directly affecting the FA. The common use of single-channel surface coils with strong RF transmit profiles for ^{13}C-MRSI enhances the importance of addressing FA calibration.

The aim is to address optimal FA calibration of ^{13}C surface coils. We characterize the spatial profile of the FA and demonstrate that it allows for a simple calibration improving the SNR.

Methods

Theory: The B_1 profile in the axial-axis of a surface loop coil is given by the Biot-Savart law. The coil transmitter voltage V required for constant FA as function of distance is:

$$V(z) = c \cdot \left(z^2 + a^2\right)^{3/2} \qquad (1)$$

where c is an acquisition- and coil-dependent constant, z is the axial-axis distance, and a is the radius of the coil loop.

From Eq. (1) the following expression can be stated:

$$V_{90}(z) = V_{90,REF} \cdot \left(\frac{z^2 + a^2}{z_{REF}^2 + a^2}\right)^{3/2} \qquad (2)$$

Using Eq. (2), with a 90° FA calibrated at a reference position through determination of $V_{90,REF}$, a calibration $V_{90}(z)$ can hereby be obtained at an arbitrary position z on the axial-axis.

Phantom experiments: To verify Eq. (2) the FA profile was characterized for three different RF surface coils using the phantom setup in Figure 1.

The coils were: 1) a dual-tuned, ^{1}H/^{13}C, transmit/receive 11 cm flex coil, 2) a ^{13}C, transmit/receive 12 cm loop coil, and 3) a ^{13}C, transmit/receive 20 cm loop coil (RAPID Biomedical). A 5.5 mL vial of 4.0 M ^{13}C-urea was used for FA calibration. All scans were performed on the integrated 3T PET/MRI system (Siemens Biograph mMR).

The vial was placed at a new position for each scan session, consisting of a localizer followed by FA calibration. For calibration a series of FID measurements with increasing transmitter voltage (10 V steps) were acquired [TR/TE 10,000/0.35 ms, FA 90°, BW 3,000 Hz, transmitter voltage 10 to 300 V (loop coils), transmitter voltage 10 to 150 V (flex coil)]. Spectra were centered on ^{13}C-urea. A sinusoidal fit of the ^{13}C-urea peak versus transmitter voltage was used to determine V_{90}. Eq. (1) was fitted to the calibration V_{90} versus position of the ^{13}C-urea vial. Experiments were repeated at different days and with different coil loads.

In vivo experiment: The feasibility of the calibration method was demonstrated in a canine cancer patient (39 kg) with a biopsy-verified axillar soft tissue sarcoma scanned as part of clinical staging work up. Patient handling and acquisition details are given in Gutte et al. 2015[1].

Hyperpolarized ^{13}C-CSI was acquired with $V_{90,REF} = 87.4$ V as measured using the calibration phantom positioned at the coil surface (equivalent to 90° at 2.3 cm). The CSI slice (13 mm slice thickness) was aligned parallel to the flex coil at a depth of 4 cm. To compensate for the FA loss a second CSI was obtained with $V_{90} = 136$ V calculated by means of Eq. (2).

Voxel-wise SNR was estimated as the total carbon signal (sum of absolute peak values for pyruvate, pyruvate-hydrate, lactate, alanine, and bicarbonate) divided by five times the spectral noise (standard deviation of the real spectrum in noise regions).

Results

Figure 2 shows an example of FA calibration measurements and sinusoidal fits at different positions of the urea vial. The resulting calibration voltage V_{90} and fits to Eq. (2) are shown in Figure 3. The fitting coefficients were: flex coil, $c = 0.1847$ V/cm^3 ($r^2 = 0.9807$); loop coil (12 cm), $c = 0.1697$ V/cm^3 ($r^2 = 0.9959$); loop coil (20 cm), $c = 0.1280$ V/cm^3 ($r^2 = 0.9681$). As can be appreciated in Figure 3 and by the r^2-values, data obtained for different days and loads follow the same curve.

Figure 4 shows SNR for the two ^{13}C-MRSI scans of the soft tissue sarcoma. The SNR improvement factor was 2.01. The noise level was constant.

Discussion

The study demonstrates feasibility of a FA calibration method for hyperpolarization studies using surface coils. Phantom experiments showed robustness of the method. Feasibility of implementation is shown in the presented canine cancer patient. However, the SNR improvement estimated to a factor 2.01 is larger than the increase in FA voltage (a factor 1.56). Therefore, the signal changes between scans cannot solely be attributed to change in FA. Tissue perfusion changes during anesthesia could also play a role.

Conclusion

The FA profile of a surface loop coil can be utilized to improve SNR for hyperpolarized ^{13}C-MRSI studies. Simple implementation and feasibility was demonstrated in a hyperpolarized ^{13}C-MRSI canine cancer patient.

Acknowledgements

References

1. Gutte H, Hansen AE, Larsen MM, et al. Simultaneous Hyperpolarized 13C-Pyruvate MRI and 18F-FDG PET (HyperPET) in 10 Dogs with Cancer. J Nucl Med. 2015;56(11):1786-1792.
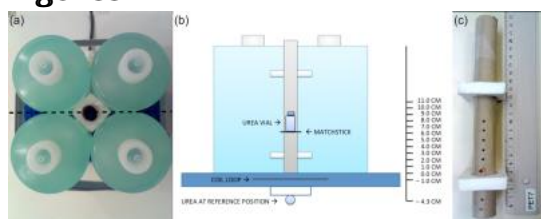
Figures

Figure 1. (a) The phantom setup consisting of four Siemens ^{1}H phantoms of 1.9 L each and the 5.5. mL ^{13}C-urea vial viewed from above with the flex coil. The broken line indicates the cross-section sketched in (b). The sketch in (b) shows the vertical scale used for the measurements with the construction in (c) in the center, which enables the change of position of the urea vial by means of moving the matchstick. The origin of the scale is located at the patient side of the coil surface.
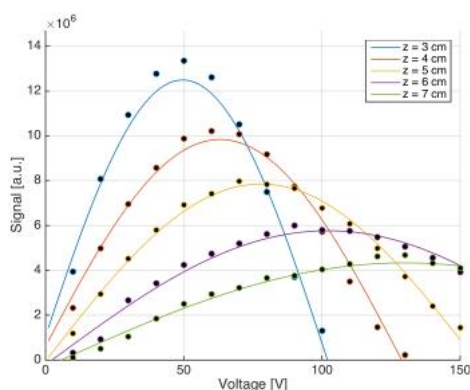

Figure 2. Flip angle calibration measurements for the 12 cm loop coil with the urea vial positioned at five different distances on the axial-axis, z, from the coil loop center.
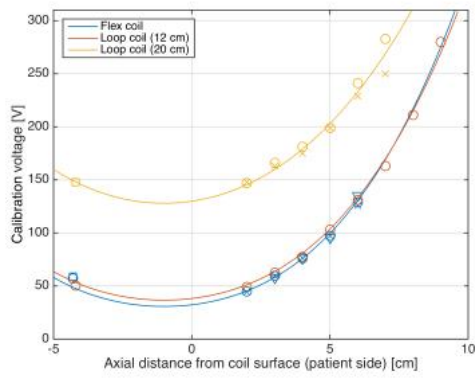
Figure 3. Calibration voltage V_{90} as a function of axial distance from the coil surface. The solid lines correspond to the function fits to Eq. (1). The loop center within each coil is located at -1.0 cm beneath the coil surface (see Figure 1). The reference position for the flex coil is located at -4.3 cm, while the reference position for the loop coils is located at -4.2 cm. The different symbols indicate different acquisition dates for each of the coils. The blue downward triangles for the flex coil indicate measurements using a smaller load.
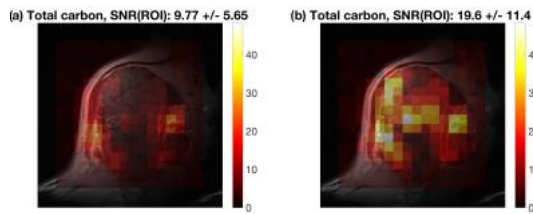

Figure 4. In vivo demonstration of the flip angle calibration method; Total carbon CSI of canine tumor (a) without and (b) with a modified calibration voltage. Mean SNR and standard deviations are given for a region-of-interest (ROI) within the tumor tissue. Mean SNR factor improvement of 2.01.