An insulated three coil set-up for MR studies on swimming fish operating in seawater

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Abstract

Heavy loading, strong RF loss and the skin effect complicate MR investigations in electric conductive, dielectric media. A set-up was developed for MR studies on swimming marine fish that reduces these limitations. A birdcage resonator adapted to high loadings was used for signal excitation. An insulated inductive coil (2 cm diameter) was fixed onto the fish and placed opposite to a watertight, passively decoupled 5 cm surface coil for signal reception. This arrangement led to enhanced penetration of the RF signal and an almost 10-fold increase in S/N ratio compared to the exclusive use of the 5 cm surface coil.

Introduction

MR measurements in electric conductive, dielectric media are complicated mainly by inductive losses. These losses originate from eddy currents induced within the sample by the oscillating field B_1. The electric conductivity decreases the signal-to-noise ratio (S/N), the loading in a coil rises. Also, pulse length or power to produce a given pulse angle increases, whereas the irradiation of radio frequencies (RF) attenuates due to the skin effect. These strong effects might even be intensified when an electric conductive medium like sea-water is flowing through an NMR probe. In this study, we present an approach for the development of an RF-coil set-up for MR measurements carried out in swimming marine fish in a horizontal MR scanner.

Materials and methods

A swim tunnel with a diameter of 15 cm was constructed that fed through a 40 cm inner diameter Bruker Biospec 47/40, operating at 4.7T. Sea-water from a freshly aerated, continuously filtered and thermostatted reservoir (10°C, volume: 1 m^3) was recirculated by a centrifugal pump, at water speeds of 0.2 to 3 m/s inside the MR scanner. Atlantic cod (*Gadus morhua*) of 35 to 52 cm body length and 0.5 to 1.1 kg body weight were placed in a Perspex chamber (of 60 cm length) closed on both sides with grids of nylon thread. The chamber with the free moving fish could be positioned right in the center of the MR scanner.

Practical considerations

The swim tunnel set-up required special considerations and demands on the functionality of MR coils. First of all the fish is surrounded by sea-water, filling the magnet bore almost completely. A resonator probe therefore must deal with a high volume of conductive, dielectric medium, even outside of the sensitive volume of the coil. Furthermore, since the swim tunnel has a fixed diameter, with the fish in the center of the tube, the optimum filling factor cannot be reached with a probe outside of the swim tunnel. In addition, the swimming movements of the fish change with the swimming velocity; therefore, MR experiments should be triggered by these movements to reduce artifacts and for the comparability of swimming performance at different swimming speeds. Furthermore, triggered NMR spectroscopy allows time resolved investigation of metabolic changes during exercise (Pörtner et al. 1998).

Results and discussion

1. A double tunable ^{1}H-^{31}P-birdcage resonator (inner diameter 19.5 cm) adapted for very high loadings was developed for signal excitation. To increase the S/N ratio the probe can be actively decoupled on both channels for use in cross-coiled experiments in combination with surface coils. The reflection was less than 2% on both channels in the swim tunnel set-up.
2. Inductive coils have the advantage, that cable connections to the preamplifier can be avoided. Fixing the coil directly on the fish prevented further interferences. Watertight 2 cm inner diameter inductive coils (^{1}H or ^{31}P) sealed in Teflon were developed for use in sea-water. One inductive coil was fixed onto one side of the animal's tail with minimal effects on the swimming performance of the fish.
3. A watertight transmit/receive ^{31}P surface coil was placed onto the inner wall of the swim tunnel opposite from the inductive coil. The coil was shaped to match the curvature of the fish, thereby improving excitation and reception (see figure 1). The matching and tuning capacitors of the coil were adjusted to the conductivity of the surrounding sea-water. Although the coil was only tuned to ^{31}P switching to ^{1}H was possible for shimming procedures. One watertight cable was fed through a watertight adapter and connected to the preamplifier of the MR scanner.
4. A differential pressure transducer fixed to the caudal fin of the fish was used to monitor tail beat pressures (Webber et al. 2001). Voltage thresholds set within the pressure pulses were used to gate the MR measurements.

The complete experimental set-up is shown in figure 1. Transversal MR images through the swim tunnel acquired with the birdcage resonator showed a very inhomogeneous excitation profile as a consequence of a strong skin effect. Using the birdcage resonator in combination with the inductive coil could reduce the attenuation of RF irradiation. A highlighted hemisphere beneath the inductive coil, delineating the excitation profile, could be identified in transversal MR images. First MR spectroscopy experiments on phantoms revealed that only the combination of all three coils obtained sufficient S/N ratios on a reasonable time scale. In particular, an increase in S/N ratio by about one order of magnitude could be reached with the three coil set-up in comparison to just the ^{31}P surface receive coil. Interestingly, water flow had no influence on spectroscopic data, whereas flow artifacts could be observed in MR images.

In conclusion, the three coil set-up in combination with the pressure transducer allowed the acquisition of gated *in vivo* ^{31}P-NMR spectra in swimming cod over 5 minutes with a reasonable S/N ratio.

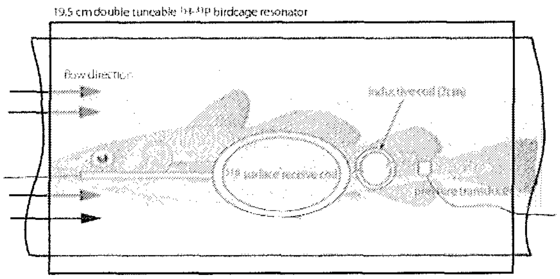

Figure 1: Three coil set-up used in MR experiments on swimming marine fish, consisting of two insulated MR coils, a birdcage resonator and the pressure transducer used for the gating of the MR measurements.

References

1. Pörtner et al. (1998) Abstract Book, ISMRM, 6th Scientific Meeting, 1803, Sydney, 18.04-24.04.98.
2. Webber et al. (2001) J. Exp. Biol. 204: 3561-3570.