Endoluminal Ultrasound Applicator with an Integrated RF Coil for High-Resolution MRI-guided HICU Thermotherapy

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Introduction

High intensity contact ultrasound (HICU) under MRI guidance may provide minimally invasive treatment of endocavitary digestive tumors in the esophagus, colon or rectum. Intraluminal transducers are introduced in the esophagus, directly contacting the target tissue and the acoustic energy delivered via this local applicator induces tissue thermal ablation [1]. An extremely accurate control of the energy deposition pattern is required to avoid the perforation of the esophagus external wall. In this context, MRI offers significant advantages, including excellent soft tissue contrast and online control of thermal dose. The objective of this work was to offer high resolution MRI guidance for accurate spatial targeting combined with active feedback control of the temperature. Miniature receive-only coils were integrated with the US transducer in a single endoscopic device.

Figure 1. *Head of the integrated endoscopic device (with the coil positioned outside the balloon).*

Methods. The endoscopic device is based on a cylindrical applicator of contact ultrasound incorporating a single element flat transducer (active zone: 8 x 15 mm², 9.45 MHz, tip cooling balloon with circulated water). The coil consists of a rectangular loop of copper wire surrounding the active HICU element (see Fig.1). Two different configurations with the coil mounted inside/outside the cooling balloon were investigated on a clinical 1.5T scanner. Morphological (T1w, IR-T1w) and temperature (PRF shift method, segmented EPI, RF spoiled gradient echo) images, for sagittal and transverse planes, were acquired on fresh samples of porcine muscle to compare the integrated coil versus a standard 4-element phased array extracorporeal coil. Standard deviation of experimental temperature data (SDT) was calculated at 10 and 20 mm distance from the surface of the tip balloon, for both cases of coil (integrated and extracorporeal).

Active temperature control experiments were conducted, in axial plane, on freshly excised porcine esophagus using the integrated coils. Temperature feedback control was based on the Fourier transformation solution of the Bio Heat Equation. Assessment of temperature controller performance was based on the correlation between a predefined target curve and the experimental temperature evolution. The temperature was actively controlled at three different locations (inner, medium and external wall) in ex vivo esophagus samples.

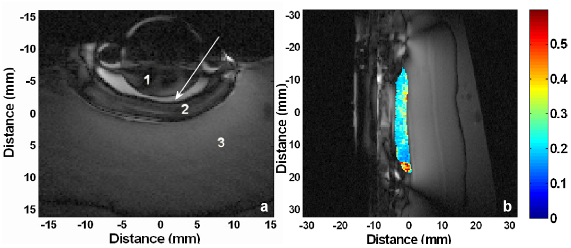

Figure 2 a).*IR-T1w image (axial plane) of esophagus (2).*
b)The same sequence (sagittal plane) with a superposed map of SDT in esophagus.

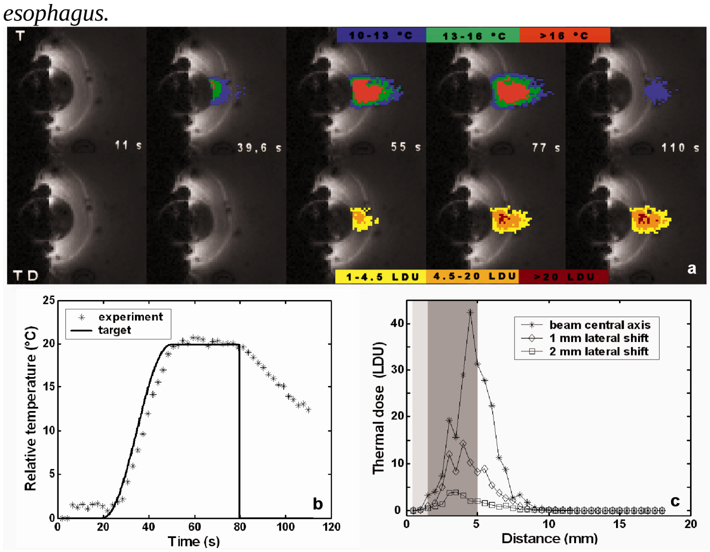

Figure 3 a).*Temperature (up) and thermal dose (down) maps for a heating experiment (active control of temperature at half depth of the esophagus wall)*
b).*Time course of the temperature evolution (same experiment).*
c).*Thermal dose control at external esophagus wall (light gray - acoustic gel, dark gray - esophagus)****.***

Results. No susceptibility or RF-related artifacts were found to corrupt the MR signal. Both miniature coils showed a similar gain in sensitivity by a factor of 7 at 10 mm depth in tissue over the extracorporeal phased-array coil. With a voxel size of 0.625x0.625x5 mm^3, the SDT was 1.9°C for the extracorporeal coil and this was improved using the integrated coil to 0.3°C (at 10 mm distance from tip balloon), and to 0.75 °C at 20 mm distance. High resolution morphological images (voxel size 0.25x0.25x3 mm^3) and accurate thermometry data (voxel size 0.5x0.5x5 mm^3, 2.2 s/image, 0.3°C average SDT) were acquired in *ex vivo* esophagus sample. The endoscopic device was operated under automatic temperature control with active feedback, showing a very accurate performance (1.7 % standard deviation, 1.1 % error of mean value, see Fig.3b). Figure 3c illustrates the thermal dose control within the esophageal distal wall. The experimental thermal dose was 31,4 LDU (Lethal Dose Unit defined as the necrosis threshold [2]) for the predefined value of 32 LDU (corresponding to the temperature controller target curve, i.e. a temperature elevation of 19.9°C over 30 s).

Discussion. The home made, miniature RF coils were designed to meet both anatomical and technical constraints. The coil mounted inside the cooling balloon offered some advantages (biocompatibility, RF pulse heating prevention). Flow artifacts due to tip cooling water could be shifted out of the region of therapeutic interest. Unlike the isotropic sensitivity of extracorporeal coil, the endocavitary coil has a significant sensitivity gradient. A sufficient SDT (up to 1°C) still could be achieved at 20 mm from the cooling balloon.

In conclusion, in this *ex vivo* study two technological issues were successfully investigated. First, an endoscopic HICU device for digestive applications was combined with a miniature receive-only RF coil. Second, this combined device was coupled to an automatic temperature controller. Available resolution of both anatomical and thermal images permitted the esophageal wall visualization. Half millimeter resolution became feasible for fast MR thermometry while providing an excellent SDT. In the future, optimized miniature receive-only RF coils will be designed for integration into cylindrical phased array US transducers.

References:

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