Endoluminal and intraductal ultrasound applicators for MR-guided hyperthermia or thermal ablation of pancreas: simulations and preliminary experiments

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Introduction: Ultrasound devices are being developed specifically for endoluminal (stomach or duodenum) and intraductal (within pancreatic duct) access for targeted thermal ablation or hyperthermia of pancreatic tumours under MR guidance and temperature monitoring.

Methods: Computer simulations based upon patient specific 3D models (with pancreatic targets) were utilized for applicator design by calculating treatment volumes as a function of transducer frequency, focusing and dimensions, sonication parameters, tissue properties, blood perfusion, and cooling flow rates necessary to protect stomach wall, duodenum, pancreatic duct and bile duct. MR-compatible devices were constructed for endoluminal (3-5 MHz planar or lightly focused rectangular elements, 12-mm OD assembly, with expandable balloon) and intraductal (6-8 MHz multi-sectored tubular elements, 2-mm catheter, 3-4 mm expandable balloon) deployment. Miniature MRI receive coils were integrated within these applicators for active tracking, positioning and alignment. The prototypes were tested in phantoms, ex vivo tissue and animal models under 3T MR temperature imaging (MRTI). The applicators were operated in thermal ablation (5-10 W, 5-10 min) and hyperthermia (2-4 W, 15-20 min) regimens.

Results: Through simulations, it was estimated that with 5-10 min exposures at 20-30 W/cm², intraductal applicators could ablate 2.3-3.4 cm diameter targets, and endoluminal applicators could ablate targets situated 2-2.5 cm away from the stomach/duodenum wall. Intraductal applicators could produce penetrating hyperthermia (>40 °C) to 15 mm radial depth. Active catheter tracking with MRI receive coils, essential for precise applicator localization and also applicator translation while treating larger targets, was successfully tested in ex vivo tissue under 3T MRI. The tracking coils on an applicator delivery catheter were precisely located in 3D coordinates using customized tracking sequences implemented in real time using RTHawk software. Endoluminal applicators delivered therapeutically significant levels of ultrasound energy through porcine stomach wall and duodenum without damaging either. During ex vivo studies (5 W, 10 min), 15-20 °C temperature increases were induced in muscle and tissue mimicking phantoms distal to stomach and duodenum samples. During initial tests, the intraductal applicators were employed to successfully ablate canine thigh muscle in vivo (2×180° applicator, 10 W, 12 min). Real time volumetric MR thermometry was obtained using RTHawk during the tests for both types of devices, and temperature measurements were made with low artifacts (SNR ~18 dB).

Conclusions: MRg endoluminal or intraductal ultrasound applicators show promise in ablation/hyperthermia of pancreatic tumors. MR guidance can be employed for positioning these devices with active tracking coils and real time temperature monitoring.

Low temperature sensitive liposomes loaded with chemotherapeutic agents (for example, Doxil by co-name) are under investigation for thermally mediated drug delivery. Ultrasound based devices for localized thermal ablation with MRI-based temperature monitoring have