Original Investigation

Thermal Field Distributions of Ablative Experiments Using Cyst-mimicking Phantoms: Comparison of Microwave and Radiofrequency Ablation

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Rationale and Objectives: The objective of this study was to explore the thermal field distribution of cystic lesions undergoing microwave ablation (MWA) and radiofrequency ablation (RFA) using in vitro phantoms.

Materials and Methods: Cyst-mimicking lesions filled with sodium chloride (NaCl) solution in acrylamide phantoms were treated with MWA and RFA in vitro. The radiofrequency electrodes or MWA antennas were implanted in the centers of the artificial cystic lesions. We used temperature fields located 5, 15, and 25 mm from the electrode or the antenna to plot the temperature-rise curves. Solid phantoms without cysts were also fabricated as controls.

Results: The temperature within cysts increased faster and reached a higher maximum temperature during MWA than during RFA, and this result was independent of the NaCl solution concentration. RFA treatment caused the temperatures within the lesion to increase significantly faster in the cysts containing 0.9% NaCl than in those containing 5.0% NaCl. However, the MWA temperature-rise curves were only weakly affected by the ionic concentration. The median temperature difference values between the 5- and 15-mm points were markedly lower in the 0.9% NaCl cyst-mimicking phantom ($P < 0.001$) than in the solid phantom after either MWA or RFA.

Conclusions: Our data indicate that MWA is a more effective technique for focal cystic lesions than RFA and has higher overall energy utilization. MWA was also less affected by the ionic concentration of the cystic fluid.

Key Words: Microwave ablation; radiofrequency ablation; phantom; experiment.

INTRODUCTION

Focal cystic lesions (FCLs) are also known as cystic or predominantly cystic neoplastic or parasitic diseases. These lesions include thyroid cysts, renal cysts, pancreatic cysts, and hepatic cystic echinococcosis. Percutaneous treatments have been used to treat these FCLs. The use of percutaneous ethanol injection is a safe and effective therapy for benign thyroid cysts and is recommended by treatment guidelines (1). Although no relevant suggestions have been proposed for thermal ablation in thyroid cystic lesions, radiofrequency ablation (RFA) is used to treat thyroid cystic lesions and has been found to lead to outcomes similar to those of percutaneous ethanol injection in prior studies (2–6). Renal cysts staged as Bosniak III and IV lesions have 16%–100% and 90%–100% risks of developing malignancy, respectively (7). RFA and microwave ablation (MWA) have been used to treat Bosniak category III or IV cystic renal tumors (8–11). Those studies have found that both RFA and MWA are safe and effective. Previous studies of pancreatic cysts have used endoscopic ultrasound-guided ablation with ethanol (and paclitaxel) (12–16). However, the complete resolution rate varied from 30% to 70% during long-term follow-up and was related to the ethanol concentration (17). One study involving the thermal ablation of pancreatic cysts has been reported; that study used RFA in ex vivo cyst models (18). Currently, puncture, aspiration, injection, and reaspiration (PAIR) is the

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accepted invasive technique for hepatic cystic echinococcosis (19). Although RFA has been used for hepatic cystic echinococcosis, the initial attempts were associated with disappointing long-term efficacy and safety profiles (20).

Both RFA and MWA have been clinically attempted in FCLs. However, no thermal field distributions of FCLs treated with RFA or MWA have been reported. Furthermore, although some studies have reported the comparison of RFA and MWA for focal solid lesions (21–23), no studies have compared the ablative effects of two techniques for FCLs. Therefore, we evaluated the thermal distribution using in vitro phantoms treated with RFA and MWA and compared the outcomes.

MATERIALS AND METHODS

Cyst-mimicking Phantom Fabrication

We used cyst-mimicking balloons with diameters of 3 cm. The balloons were washed repeatedly with distilled water. Rubber latex balloons filled with sodium chloride (NaCl) solutions of different concentrations (0.9% or 5.0%) were created to mimic cystic lesions. In total, 12 cyst-mimicking balloons were made for the experiment; six balloons were filled with 0.9% NaCl, and six were filled with 5.0% NaCl.

The cyst-mimicking balloons were embedded into tissue-mimicking gel. The recipe and the fabrication method of the tissue-mimicking gel were modified from the experiment reported by Bu-Lin et al. (24). Table 1 shows the reagents used to obtain this tissue-mimicking gel (1800 mL). The gel was prepared using a 0.2-M citrate buffer with pH 4.3. All ingredients shown in Table 1 were added sequentially into a rectangular parallelepiped mold (2100 mL, 20.0 cm × 15.0 cm × 7.0 cm). The solution was stirred with a glass rod until the ingredients were totally dissolved in 1800 mL of deionized water. Then, a cyst-mimicking balloon was placed in the center of the solution by clamping it with two glass rods. The distance between the bottom of the balloon and the bottom of the mold was 4 cm. Subsequently, we added the initiator-activator pair into the solution under stirring. The solution became a colorless transparent gel after 15 minutes. After 10 minutes, the solution was stable enough to fix the cyst-mimicking balloon, and the two glass rods were removed immediately. Then, the cyst-mimicking balloon was fixed, and the traces left by the two glass rods were filled in by the gradually forming gel. During the gel formation process, heat is produced, raising the temperature of the phantom gel. Therefore, we cooled the phantom to room temperature (approximately 20°C) until the process was complete, and cooling was no longer needed.

TABLE 1. The Reagents Used to Prepare the Tissue-mimicking Gel with a Citrate Buffer Concentration of 0.2 M and pH of 4.3 (1800 mL)

Ingredients	Dosage
Citric acid monohydrous	44.82 g
Sodium citrate tribasic dehydrate	43.15 g
Acrylamide	171.00 g
N,N-Methylene-bis-acrylamide	9.00 g
Glycerol	108.00 mL
Deionized water	Top up to 1800 mL
Initiator-Activator Pair	
L-Ascorbic acid	1.80 g
1% $FeSO_4$	4.50 mL
3% H_2O_2	5.40 mL

We prepared 12 cyst-mimicking phantoms as described previously. Six phantoms were embedded with cyst-mimicking balloons of 0.9% NaCl solution (three for MWA and three for RFA) and six with cyst-mimicking balloons containing 5.0% NaCl solution (three for MWA and three for RFA).

Solid Phantom Fabrication

The reagents and fabrication method of the solid phantom were the same as those used to prepare the tissue-mimicking gel. The only difference was that no cyst-mimicking balloon was embedded.

Six solid phantoms (three for MWA and three for RFA) were prepared.

Ablation Systems

The Cool-Tip radiofrequency (RF) system (Valleylab, Boulder, CO) was used for RFA. This system consists of the following parts: the RF generator (peak power output: 200 W, electric current: 480 kHz), a peristaltic perfusion pump, inflow and outflow tubing, an electrode, and a grounding pad. During ablation, the monopolar electrode, which consists of a hollow 17-gauge needle with an exposed 2-cm tip, was cooled via the internal circulation of sterile chilled water (4°C) at a flow rate of approximately 100 mL/min.

The Kang-You MWA system (Kang-You, Microwave Electronic Institute, Nanjing, China) was used for MWA. This system consists of the following parts: an MTC-3 microwave generator (frequency: 2.45 GHz, power output: 5–100 W), a flexible low-loss cable, a 14-gauge cooled-shaft antenna, and a steady-flow pump. The antenna was divided into three parts: a 10-cm-long cable connection portion, a 15.0-cm-long shaft coated with Teflon, and a 1.1-cm-long active tip coated with polytetrafluoroethylene. During the MWA treatment, the steady-flow pump circulated sterile chilled water (4°C) within the lumen of the antenna shaft at 50–60 mL/min to maintain the shaft at a relatively low temperature.

Ablation Experiment

Both RFA and MWA were performed in 0.9% NaCl cyst-mimicking phantoms and 5.0% NaCl cyst-mimicking