Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.JournalofSurgicalResearch.com

Evaluation of probe angles for synchronous waveform 915-MHz microwave ablation

Yan Li, PhD,[a] Megan Stevenson, MD,[a] Jack W. Rostas, MD,[a] Harshul Pandit, MS,[a] Su Ping Li, BS,[a] Farrah J. Wolf, MD,[b] Damian E. Dupuy, MD,[b] and Robert C.G. Martin, MD[a,*]

[a] Division of Surgical Oncology, Department of Surgery, University of Louisville, Louisville, Kentucky
[b] Rhode Island Hospital/Warren Alpert Medical School of Brown University, Providence, Rhode Island

ARTICLE INFO

Article history:
Received 21 December 2017
Received in revised form
23 April 2018
Accepted 23 May 2018
Available online xxx

Keywords:
Microwave ablation
Surgical devices
Tumor ablation

ABSTRACT

Background: The purpose of this study is to compare the ablation performance between a synchronous microwave ablation (MWA) system and a commercially available asynchronous system in *ex vivo* bovine liver and evaluate the efficacy of ablation at varying entrance angles.
Materials and methods: Two 915-MHz MWA systems were used in bench top *ex vivo* bovine livers with various conditions (synchronous *versus* asynchronous). Using synchronous technology ablations to liver, kidney, or lung at angles of 0, 15, 30, and 90° were evaluated.
Results: Synchronous and asynchronous MWA systems created mean ablation zone volumes of 26.4 and 15.8 cm^3, 62.9 and 45.4 cm^3, 90.8 and 56.4, and 75.7 and 54.8 cm^3 with single, double (2 microwave probes in use simultaneous) (2 cm spacing), and triple (three probes in use simultaneously) (2 cm and 3 cm spacing) antennae configurations, respectively; adjusted *P*-values $\leq$ 0.006. Ablation defects were similar across all groups when evaluated for entrance angle. Specifically, when comparing 0-degree angle to all other angles, achieved zones of ablation (ZA) were similar (mean $\pm$ standard deviation for 0-degree *versus* all other angles: 8.72 $\pm$ 4.84 *versus* 9.38 $\pm$ 4.11 cm^2, $P = 0.75$). The use of the long-tip probe resulted in a statistically significant increase in the achieved ZA when compared to the short tip probe (10.9 $\pm$ 4.3 *versus* 6.5 $\pm$ 2.4, respectively; $P = 0.01$).
Conclusions: Newly developed synchronous microwave technology creates significantly larger ablation zones when compared to an existing asynchronous commercially available system. The angle of approach does not affect the resulting ZA. This is clinically relevant as true 0-degree angle is often difficult to obtain.

Introduction

Thermal ablation for various malignant tumors has emerged as an effective treatment modality for neoplasms not amenable to resection. The potential target population is large: patients with anatomically unresectable tumors, preoperatively predicted inadequate functional liver remnant, metastatic disease, and those medically unfit for surgery are examples. The initial enthusiasm for radiofrequency ablation (RFA) has tempered with time due to some of its well-described limitations. RFA relies on an electrical circuit, and increasing temperatures result in boiling and charring, which produces impedance and limits the effectiveness of ablation.[1] It does not perform well in close proximity to vasculature due

* *Corresponding author*. Department of Surgery, Division of Surgical Oncology, University of Louisville, 315 E. Broadway - #312, Louisville, KY 40202. Tel.: +502 629-3355; fax: +502 629-3030.
E-mail address: robert.martin@louisville.edu (R.C.G. Martin).
0022-4804/$ – see front matter
https://doi.org/10.1016/j.jss.2018.05.043

to the cooling or heat-sink effect of local blood flow[2-4] and is time consuming, especially with single-probe use. Taken together, these properties of RFA have resulted in ablations with varying efficacies and often high recurrence rates. Many of these limitations are inherently addressed in microwave ablation (MWA), which has developed more recently and gaining in popularity.

MWA utilizes electromagnetic radiation to heat intracellular water molecules which causes coagulative necrosis.[5] It has the advantage of larger and faster volumes of thermal energy delivered to tissues without reliance on an electrical circuit, allowing for multiple simultaneous treatments, higher temperatures, less impedance, and larger ablation zones.[1,6] The resulting ablation defects are more consistent and reproducible, especially with larger tumor sizes. Cooled-shaft antennas have been introduced for MWA and shown to be effective for reducing skin burns,[6,7] and lower frequency systems (915 *versus* 2450 MHz) have been shown to penetrate tissue more deeply with less attenuation and theoretically a larger ablation zone.[6,8,9]

A newly developed synchronous MWA technology that is in limited clinical use may create larger ablation zones than those created by commercially available asynchronous systems when using single or multiple antenna arrays. In addition, traditionally in MWA, multiprobe use has been designed with probes placed in parallel to each other. In reality, tissue ablation at a true 0-degree angle is variable and affected by tumor location, patient body habitus, and choice of access (laparoscopic *versus* open *versus* percutaneous), among other variables. Additionally, low-volume ablators (surgeons typically performing MWA less than 20 times per year) typically have a more difficult time attaining this angle. It is unknown whether a true 0-degree angle is actually essential to obtaining a quality ablation. Certainly, more flexibility in the angle of approach would facilitate effective ablation in difficult clinical scenarios, as well as make MWA more user-friendly for the beginning user. Thus, the purpose of this study is to compare the ablation performance between a synchronous MWA system and a commercially available asynchronous system in *ex vivo* bovine liver and to evaluate and compare varying entrance angles of MWA probes for their effectiveness in achieving acceptable zones of ablation (ZA). To our knowledge, no animal models to date have specifically evaluated the effect of varying probe entrance angles on the resulting ZA.

Materials and methods

Synchronous and asynchronous ablation methods

Two 915-MHz MWA systems were used. A single three-channel–synchronized generator (MicroThermX Microwave Ablation System, Perseon Medical Salt Lake City, UT) and up to three asynchronized microwave generators Evident (Covidien, Boulder, CO), each set to 45 Watts, powered percutaneously designed 14.5-gauge, 3.5-cm active-tip microwave antennae. The MicroThermX Microwave Ablation System employs a Synchronous Wave Alignment, which theoretically allows two (or more) antennas to emit microwaves in-time and in-phase and thus reinforce each other (Supplemental Fig. 1), allowing for a larger ablation area (Supplemental Fig. 2). Matrix gel ablations were performed at 3-cm spacing at multiple time points for both devices. Matrix Gel was used to allow for superior visualization of ZA with asynchronous *versus* synchronous waves (i.e., volume and contiguous or noncontiguous). Bench top *en bloc* bovine livers were maintained at 15.5°C-19.3°C (mean 16.8 C). Bovine livers were utilized since they are readily available and allowed more permutations in spacing. Each of the four conditions could be repeated six times, for a total of 48 ablations across fairly uniform liver parenchyma. Tested conditions included single, double (2-cm spacing), and triple (2- and 3-cm spacing) microwave antennae configurations. Each condition (single 10-min application) was repeated six times for each of the two ablation systems ($n = 48$ ablations). Three-dimensional spacing guides, with system-specific designs, were used for all ablations requiring more than a single antenna.

Ablated tissue was resected from the *en bloc* specimens at the conclusion of each treatment. Ablation zones were measured in three dimensions, and volumes were estimated. Statistical analysis was performed. Systems and tested conditions were compared using analysis of variance with follow-up comparisons adjusted using the Holm test (adjusted P-values < 0.05).

Angle of ablation methods

The MicroThermX Microwave Ablation System used in this study is a single-generator/single-amplifier device with a frequency of 915 MHz. Nonparallel probe placement was a central component to the design of the MicroThermX, as clinically it is often difficult to achieve parallel probe placement; in preclinical evaluation, these nonparallel probes have been equally efficacious at achieving tissue ablation. The antenna shaft is centrally cooled, which minimizes the risk of both skin burns and unwanted tract ablation. Two separate SynchroWave antennas have been designed, both 14-gauge needles with a sharp trocar tip. Both have easily visible labeling along the shaft to insert the antenna to the correct depth. A short tip (ST 2.0-cm active length) and a long tip (LT, 4.1 cm) have been designed for smaller and larger planned ablations, respectively (Fig. 1). Both were used in this study.

Animals and operative technique

This good laboratory practice study was consistent with the conduct of other studies of this type and approved by the University of Louisville Institutional Animal Care and Use Committee. Eight adult pigs were fasted overnight, and then were anesthetized with a mixed injection of atropine, dexmedetomidine, ketamine, and butorphanol. General anesthesia was maintained with isoflurane via endotracheal tube. Analgesia in the form of buprenorphine-sustained release was administered subcutaneously immediately preoperatively, to last 48-72 h postoperatively. Additional analgesia (Meloxicam) was also administered both preoperatively and postoperatively. The pigs then underwent either open ($n = 6$, via a small abdominal incision appropriate for passage of both ultrasound and the MWA probes) or laparoscopic ($n = 2$, via trocars) ablations to the liver, kidney, or lung, and they were randomly assigned to predetermined entrance angles of 0, 15,