Microwave Ablation and IRE

Damian E. Dupuy, M.D., FACR
Professor Diagnostic Imaging
Brown Medical School
Director of Tumor Ablation
Rhode Island Hospital

BROWN
Alpert Medical School
Disclosures

Consultant
- Veran Medical Technologies, Inc
- Ethicon Endosurgery
- BSD Medical
- Covidien

Grant Support
- ACRIN
- ACOSOG
- Veran Medical Technologies, Inc
- Mayo Clinic/Endocare
- AngioDynamics
- MedWaves
- Biotex
Learning Objectives

• Explain current MWA technology and potential advantages
• Discuss principles of IRE
• Show early data, clinical and preclinical examples.
Background

Heat - Kinetic Energy

Heat → Kinetic Energy
Non-telecommunication MW Systems

- Only allowed certain frequencies depending on International Telecommunication Union (ITU)
Industrial, Scientific, Medical (ISM) Bands

- 915 and 2450mHz available in North America, Asia, Europe
Advantages of MWA Compared with RFA

• Shorter ablation times
• Larger ablation volumes
• Less nerve stimulation
# MWA vs. RFA

<table>
<thead>
<tr>
<th></th>
<th>Microwave (n = 40)</th>
<th>Radiofrequency ablation (n = 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. tumors</td>
<td>1–2</td>
<td>1–2</td>
</tr>
<tr>
<td>Ablation success</td>
<td>98%</td>
<td>92%</td>
</tr>
<tr>
<td>Ablation recurrence</td>
<td>2%</td>
<td>17%</td>
</tr>
<tr>
<td>Ablation time (min)</td>
<td>13</td>
<td>40 (20–65)</td>
</tr>
<tr>
<td>OR time</td>
<td>56.9 (23.8–1256)</td>
<td>125.8 (21.2–243.6)</td>
</tr>
<tr>
<td>OR charges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median (range)</td>
<td>$13,389 ($8059–18,136)</td>
<td>$25,687 ($19,410–40,235)</td>
</tr>
<tr>
<td>OR variable direct charges</td>
<td>$909 ($562–1420)</td>
<td>$2903 ($2052–4503)</td>
</tr>
<tr>
<td>OR fixed direct charges</td>
<td>$514 ($337–628)</td>
<td>$787 ($565–1305)</td>
</tr>
</tbody>
</table>

*Martin et al, Ann Surg Oncol, August 2009*
Martin et al MWA vs. RFA
Time=$Money$

- Mean MWA ablation time 13 min vs. 40 for RFA
- OR time 50% less with MWA
- Median MWA OR charges $\frac{1}{2}$ of RFA
- MWA recurrences 2% vs. 17% with RFA
Microwave Ablation Factors

- Microwave antenna transforms electrical current to broadcast electromagnetic field about itself which interacts with its environment.
- Therefore antenna design needs to consider following factors:
  - operating frequency and
  - permittivity of its environment.
- Tissue is a lossy environment where permittivity changes during ablation.
- Changes in permittivity can affect forward power transformation efficiency and impede power broadcast to surrounding tissue.
- This can result in antenna and transmission line heating that
  - chars tissue adjacent to the antenna and
  - elongation or movement of field that can produce unwanted regions of thermocoagulation.
MW Systems
Percutaneous Applicators

- 2450mHz
  - Neuwave
  - Acculis
  - HS (Forea) FDA Approved

- 915mHz
  - Covidien
  - MedWaves FDA Approved
  - BSD Medical
Evident MW System

- 14 gauge
- 12, 17, 22cm lengths
- Cooled needle and Cable
- 915mHz, 45W at generator
- ~5.5cm in 10min-3 applicators 2.0cm spacing
- Commercially available
Acculis
2450mHz System

- 1.8mm Diameter
- 14cm and 29cm lengths
- Cooled needle and Cable
- 2.45 GHz, 180W at generator
- 5.5cm in 6 minutes
- Q2 2010 Commercial Release
Neuwave Certus 140 MWA System

- $\text{CO}_2$ cooled needle and Cable
- 2.45 GHz, 140W, 3 generators
- Measures temp
- $\sim3 \times 4\text{cm}$ ablation in 5 min
- Commercial Release 2010?
MedWaves
915mHz MW System

- 14 gauge
- 15, 20cm lengths
- No cooling needed
- 915mHz, 32Watt generator
- Measures reflectivity and temperature
- 5 x 4cm in 10min-1 applicator
- FDA approved and available at select centers
68 yo Woman with Pancoast Tumor
68 yo Woman with Pancoast Tumor
68 yo Woman with Pancoast Tumor

3 MedWaves Antennae

10 min treatment time 12-32 Watts
68 yo Woman with Pancoast Tumor
68 yo Woman with Pancoast Tumor

total lesion volume = 404.815 cm³  treated volume = 245.084 cm³

Fusion Image
9cm Recurrent Squamous Cell CA

Necrotic center
9cm SQCCA

CT-guided MWA 3 Evident antennae
10 min x 2
Large Renal Cell carcinoma

2 yrs S/P MWA

CT-guided MWA 3 Evident antennae 10 min
MWA of Lung Neoplasms
Cancer Specific Survival

76% 2 Year Survival

Wolf et al. Radiology 2008
Results

Survival

Cancer-Specific Mortality

Wolf et al RSNA 2009

\[ P = .001 \]

\[ P = .71 \]
MWA
Advantages

• Multiple applicators increase flexibility of treatment
• Large volumes in shorter time periods
• Heat sink effect may not be as apparent as RFA
• ? Improved penetration in lung tissue, Potentially
• Direct comparison with RFA unknown at present
• Appears to be less painful c/w RFA
Irreversible Electroporation Overview

• Small (16-18G) needle electrodes placed with CT/US guidance
• Very short high DC current (2500–3000 volt) pulses create holes in cell membranes that lead to apoptosis in 2 hrs.
• Rapid non-thermal treatment delivery
Irreversible Electroporation

Technique that increases the permeability of cell membranes by changing the transmembrane potential resulting in disruption of the cell membrane.

Application of short pulse high-voltage DC current.
**NanoKnife IRE Generator**

- Portable light weight similar to US unit
- Upgradeable Windows OS
- USB data export
- Fail safe electric shut-off system
- EKG cardiac synchronization
- 6 electrode ports

*AngioDynamics, Queensbury, NY*
IRE Electrodes

Monopolar

Bipolar
IRE Electric Field Changes for 2 and 4 Monopolar Configurations

680v/cm=cell death=solid line

Annals of Biomedical Engineering 2005;33:223-231
Two Monopolar Electrodes

- 2 cm exposure & 1.5 cm spacing @ 2,500 volts
Bipolar Electrode

- 15mm x 29mm Treatment Zone @ 2,700 volts with 70 usec pulse width
Irreversible Electroporation
Overview

• Collagenous architecture spared
• Dead cells resorbed by body with no foreign body reaction like RFA/MWA/Laser
• Minimal tissue distortion
• Post-procedural pain minimal since non-thermal
• Need to perform under GA with neuromuscular blockade
Cardiac Synchronization

- High current pulses may stimulate cardiac conduction system
- Tachyarrhythmias reported in IRE procedures near heart
- Cardiac synchronization delivers IRE current during refractory period
Irreversible Electroporation in Swine Lung
IRE Lesions
Swine Lung - 4 weeks

Bipolar Lesion
Monopolar Lesion
IRE lesion
Swine Lung
IRE Liver
Liver IRE

TTC Fresh

TTC Fixed
Liver IRE

x 4  x 10
Liver IRE

x 4

x 20
IRE Liver

vein

x 20
<table>
<thead>
<tr>
<th>Location</th>
<th>N</th>
<th>Probe</th>
<th>Spacing</th>
<th>Exposure</th>
<th>Voltage</th>
<th>Reverse polarity</th>
<th>Ablation Zone (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-hepatic</td>
<td>4</td>
<td>2 mono</td>
<td>2 cm</td>
<td>2 cm</td>
<td>3,000</td>
<td>yes</td>
<td>3.25 +/- 0.35 x 1.45 +/- 0.21</td>
</tr>
<tr>
<td>Intra-hepatic</td>
<td>9</td>
<td>2 mono</td>
<td>2 cm</td>
<td>2.5 cm</td>
<td>2,500</td>
<td>yes</td>
<td>2.95 +/- 0.31 x 1.5 +/- 0.44</td>
</tr>
<tr>
<td>Intra-hepatic</td>
<td>3</td>
<td>2 mono</td>
<td>2 cm</td>
<td>2.5 cm</td>
<td>3,000</td>
<td>No</td>
<td>2.27 +/- 0.23 x 1.5 +/- 0.2</td>
</tr>
<tr>
<td>portal</td>
<td>4</td>
<td>2 mono</td>
<td>2 cm</td>
<td>2 cm</td>
<td>3,000</td>
<td>yes</td>
<td>4.45 +/- 0.07 x 1.8 +/- 0</td>
</tr>
</tbody>
</table>

Liver IRE
IRE Pancreas

X20 duct and vessel
Conclusions

• IRE creates well defined areas of cell kill unaffected by heat sink effects
• Airways, bile ducts, vessels remain patent
• Potential applications in high heat sink areas and near critical structures
• Need to use GA with neuromuscular blockade and cardiac synchronization
• No human data currently just anecdotal cases
• Human trials in and outside US beginning