Minimally Invasive Focused Ultrasound for Ablative Neuro-Oncology: Design and Fabrication

Nao J Gamo\(^1\), Rajiv Iyer\(^2\), Xiaoxuan Zhang\(^1\), Nicholas Ellens\(^3\), Micah Belzberg\(^2\), Youseph Yazdi\(^1\), Jeffrey Siwerdsen\(^{1,3}\)
Alan R. Cohen\(^2\), Henry Brem\(^2\), Mari Groves\(^2\), Amir Manbachi\(^{1,2}\)

1 Department of Biomedical Engineering
2 Department of Neurosurgery
3 Department of Radiology and Radiological Science
Johns Hopkins University
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Inventions
- US 61/781,032, filed 2014
- US 62/464,511, filed 2018
**Introduction: Focused Ultrasound in Neurosurgery**

Focused ultrasound: tumor ablation  
Soft tissue: prostate, breast, liver, and kidney cancer

Transcranial HIFU: through an intact skull  
Skull bone: wave distortion, high attenuation  
Large-scale, high-power (650-800W)\(^1\)  
Phase correction, MR thermometry\(^2\)

Intracranial, low-power HIFU  
Common minimally invasive intervention  
Precise and effective thermal ablation

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\(^1\) McDannold et al., Neurosurgery, 2010  
\(^2\) Hynynen et al., MRM, 2004
Design Constraints and Development

**Minimally invasive approach**

Lateral ventricle volume
- Average size: 16.4 ± 4.7 mL
- Frontal horn diameter 1.5 cm x 5 cm

Extra-calvarial ventricular access
- (A) Kocher’s point (burr hole diameter 1-1.5 cm)
- (B) Keen’s point
- (C) Dandy’s point

**Device schematics**

Minimally invasive focused ultrasound (MIFU)
- Multiple insertion trajectories
- Diagnostic and therapeutic component
- Use with temperature monitoring system

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1. Zhu et al., JMRI, 2006
2. Miller P., MIFUS of Brain [ppt], 2016
3. Mortazavi et al., Childs Nerv Syst, 2013
Propagation Medium and Ultrasound Model

Acoustic Pressure Profile
Westervelt Equation

Temperature Distribution
Pennes’ Bioheat Transfer Function

Dosage Calculation
Thermal Dose Function

Target temperature: 65 °C
Sonication time: 5 sec
Cooling period: 90 sec

Mechanical and Electronic Focusing
Source Frequency
Focusing location

<table>
<thead>
<tr>
<th>Medium</th>
<th>𝜌↓𝑡</th>
<th>𝐶↓𝑡</th>
<th>𝜕𝑇/𝜕𝑡</th>
<th>𝑘↓𝑡</th>
<th>𝛻↑2𝑇</th>
<th>𝜌↓𝑏</th>
<th>𝐶↓𝑏</th>
<th>𝑤(𝑇−𝑇↓0)</th>
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<td>1545</td>
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<td>CSF</td>
<td>995</td>
<td>1510</td>
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</table>

|                | 5.30 | 3640 | 0.54   | 2.65×10⁻² | 4200 | 0.62 |

1 Westervelt, J. Acoust. Soc. Amer., 1963
2 Pennes, J. Appl. Physiol., 1948
3 Sapareto and Dewey, Int J ROBP, 1984
5 Zhang, X et al. AAPM 2017
Solution Concepts: Two Variations in Design

Side viewing

Forward viewing
Side-viewing transducers: DFM (Design For Manufacturing)

Therapeutic element
SCI’s H-245
f = 1.5 MHz, 45 mm radius of curvature
Rectangular aperture of 9 x 32 mm

Imaging
SCI’s IP-105
Specifications of the therapeutic transducer

SCI (SonicConcept Inc)’s H-245 transducer:
(A) Frequency = 1.5 MHz
(B) Radius of curvature = 45 mm
(C) Rectangular aperture of 9 x 32 mm.
(D) Pressure focal gain of 6.7 kPa, assuming 1 at the radiating surface.

Power consideration:
H-245 transducer can handle 300 Watts of power.
(e.g. 300 Watts peak at 50% duty cycle, or 150 Watts CW).
Future Directions

(1) Finishing Prototyping
    according to the specifications described previously

(2) Probe Functionalization (i.e. Software development)
    Vantage 64 (to drive the imaging array, IP-105)
    TPO-105 to drive 4-channels of HPO-245 (300 Watts)
Future Directions

(3) Cadaver Tests

Evaluation of whether the probe inserted within the ventricles can ablate with the following criteria

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Axial dimension of lesion</td>
<td>10-20 mm</td>
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<tr>
<td>Lateral dimension of lesion</td>
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<tr>
<td>Temperature</td>
<td>65°C</td>
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<tr>
<td>Power</td>
<td>10-60 W</td>
</tr>
<tr>
<td>Frequency</td>
<td>1.5-3 MHz</td>
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<tr>
<td>Sonication time</td>
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<tr>
<td>Cooling time</td>
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<tr>
<td>Mechanical index</td>
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