Stimulating Bone Growth Using Piezoelectric Ultrasound Transducers on the Edentulous Jaw

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Joseph Ouellette
Sarah Roberge
Introduction

- Edentulous patients lack the mechanical stress to maintain bone density
- Ultrasound stimulates bone growth
- Design mouthpiece that produces ultrasound
# Trends in Edentulism

<table>
<thead>
<tr>
<th>Age group (y)</th>
<th>Dentures needed</th>
<th>1991</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
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<tbody>
<tr>
<td>Complete maxillary</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
<td>0.8</td>
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<tr>
<td>25-34 Complete mandibular</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Both</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
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<tr>
<td>Complete maxillary</td>
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<td>4.9</td>
<td>4.4</td>
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<tr>
<td>35-44 Complete mandibular</td>
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<tr>
<td>Both</td>
<td>4.2</td>
<td>3.7</td>
<td>3.2</td>
<td>2.8</td>
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<tr>
<td>Complete maxillary</td>
<td>11.4</td>
<td>10.3</td>
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<tr>
<td>45-54 Complete mandibular</td>
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<tr>
<td>Both</td>
<td>10.4</td>
<td>9.4</td>
<td>8.4</td>
<td>7.4</td>
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<tr>
<td>Complete maxillary</td>
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<td>12.3</td>
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<tr>
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<td>0.3</td>
<td>0.2</td>
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<td>Both</td>
<td>20.7</td>
<td>18.6</td>
<td>16.5</td>
<td>14.5</td>
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<tr>
<td>Complete maxillary</td>
<td>12.8</td>
<td>11.5</td>
<td>10.2</td>
<td>8.9</td>
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<tr>
<td>65-74 Complete mandibular</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
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<td>Both</td>
<td>28.5</td>
<td>25.6</td>
<td>22.8</td>
<td>19.9</td>
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<tr>
<td>Complete maxillary</td>
<td>14.7</td>
<td>13.2</td>
<td>11.7</td>
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<tr>
<td>75+ Complete mandibular</td>
<td>1.2</td>
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<td>0.5</td>
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<tr>
<td>Both</td>
<td>43.9</td>
<td>39.5</td>
<td>35.1</td>
<td>30.7</td>
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</tbody>
</table>

**Table IV.** Number of U.S. adults (in thousands) who need 1 or 2 dentures

<table>
<thead>
<tr>
<th>Age group (y)</th>
<th>1991</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-34</td>
<td>858</td>
<td>670</td>
<td>613</td>
<td>601</td>
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<tr>
<td>35-44</td>
<td>3,770</td>
<td>3,841</td>
<td>2,928</td>
<td>2,614</td>
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<td>45-54</td>
<td>5,612</td>
<td>7,332</td>
<td>7,711</td>
<td>5,850</td>
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<tr>
<td>55-64</td>
<td>7,667</td>
<td>7,836</td>
<td>10,232</td>
<td>10,595</td>
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<td>65-74</td>
<td>7,675</td>
<td>6,837</td>
<td>7,054</td>
<td>9,164</td>
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<tr>
<td>75-84</td>
<td>6,166</td>
<td>6,613</td>
<td>5,934</td>
<td>6,381</td>
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<tr>
<td>85+</td>
<td>1,900</td>
<td>2,287</td>
<td>2,654</td>
<td>2,681</td>
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<tr>
<td>Total number of adults</td>
<td>33,648</td>
<td>35,416</td>
<td>37,126</td>
<td>37,886</td>
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<tr>
<td>Demand at 90% utilization</td>
<td>30,283</td>
<td>31,874</td>
<td>33,413</td>
<td>34,097</td>
</tr>
<tr>
<td>Total number of edentulous arches</td>
<td>53,839</td>
<td>56,493</td>
<td>59,265</td>
<td>61,043</td>
</tr>
</tbody>
</table>

Previous Work

- **Ultreo Ultrasound Toothbrush**
- **Patent # 7,037,270** – Small ultrasound transducers
- **University of Alberta: Low-Intensity Pulsed Ultrasound Device (LIPUS)**
  - Aims to regrow teeth
  - Operates for 20 minutes per day

Bone Remodeling

- Osteocytes act as mechanoreceptors
- Biochemical reactions
- Osteoclasts – resorb bone
- Osteoblasts – rebuild bone
- Edentulism – no mechanical stimulation from teeth

http://cellbio.utmb.edu/microanatomy/bone/cartilage_and_bone_cells.htm
Wnt Signaling

- Monitoring molecular pathway for bone synthesis
- Chemical pathway
  - Mechanical stress
  - Wnt messenger molecule
  - β-catenin
- Gene Transcription

<table>
<thead>
<tr>
<th>Lineage:</th>
<th>Mesenchymal Stem Cell</th>
<th>Pre-Osteoblast I</th>
<th>Pre-Osteoblast II</th>
<th>Osteoblast</th>
<th>Mature Osteoblast</th>
<th>Osteocyte</th>
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</thead>
<tbody>
<tr>
<td>Transgene for:</td>
<td>SMA</td>
<td>Cbfal/Runx2</td>
<td>Osterix</td>
<td>Col1 3.6kB</td>
<td>Col1 2.3kB</td>
<td>DMP1</td>
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<tr>
<td>Color:</td>
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<td>None</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
<td>Red</td>
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<tr>
<td>Antibodies to:</td>
<td>Stro-1 +</td>
<td>Runx2+</td>
<td>Osterix +</td>
<td></td>
<td></td>
<td>Alk. Phos. + Osteocalcin +</td>
</tr>
</tbody>
</table>
Electric Circuit

- Voltage oscillator
  - Creates a voltage signal with specific frequency
  - Typically has quartz crystal
  - Low power
- \( P = V \cdot I \)
Electric Circuit

- **Power amplifier**
  - Converts low power signal into high power signal
  - i.e. increases voltage and current amplitude

- **MOSFET**
  - metal–oxide–semiconductor field-effect transistor
Electric Circuit

- **Constraints**
  - 18 watts
  - 9 Volt battery

- **Design**
  - Boost converter
  - Inductor principle
Electric Circuit

- Multisim Simulation
  - Bode plot
  - Phase shift
  - Power output
- Circuit Produces
  - 18 Watts
  - 1 MHz
Electric Circuit

- Battery
- Transducer
- Inductor
- MOSFET
- Voltage Oscillator
Transducer Operation

- **Piezoelectric**
  - Barium Titanate
    - Crystalline structure
    - Changes volume to external voltage

- **Transducer**
  - Converts voltage signal into mechanical
  - Ultrasound

![Diagram of transducer operation](image)
Transducer Fabrication

- Aluminum Mold
  - Transducer for animal test
  - Built at machine shop
- Transducer
  - 40% weight Barium Titanate
  - 60% weight Polyethylene glycol
  - Melted and poured into mold
  - Sintered at 1200C
  - Poled at 1000V
  - Coated in gold palladium
Transducer Fabrication

- Oven
  - Sintering of Barium Titanate/PEG mixture
- Archimedes Principle
  - Measuring density
- 240A power supply
  - Polarizing transducer
Animal Testing

- BatGal Transgenic Mice
- Transducers – 10 minutes, once a day
- Measure gene activity (β-Gal)
- Measure bone growth (x-ray, double labeling)
- Sunil Wadhwa, D.D.S., Ph.D.

http://www.ars.usda.gov/is/pr/2005/050921.htm
Finite Element Analysis

- Simulia’s Abaqus
  - Simulate Ultrasound Propagation
  - Human and Mouse models
  - Gum and bone under ultrasound stimulation
- Analyze effectiveness of the device
  - Inspect for errors before conducting trials
Mouthpiece Design

- Made with polyurethane
- Transducers in mouthpiece
- External Circuit
## Budget

<table>
<thead>
<tr>
<th>Product</th>
<th>Price</th>
<th>Quantity</th>
<th>Total Price</th>
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<tbody>
<tr>
<td>Circuit</td>
<td>$200</td>
<td>1</td>
<td>$200</td>
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<tr>
<td>Barium Titanate</td>
<td>$200/1kg</td>
<td>2kg</td>
<td>$400</td>
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<tr>
<td>Mold for Transducer</td>
<td>$52.86</td>
<td>2</td>
<td>$105.72</td>
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<tr>
<td>Gold Palladium Spluttering</td>
<td>$6/transducer</td>
<td>25</td>
<td>$150</td>
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<tr>
<td>Sintering</td>
<td>$10/hour</td>
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<td>$100</td>
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<tr>
<td>BetaGal Mice</td>
<td>$255</td>
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<td>$510</td>
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<tr>
<td>Mouse Surgical Tools</td>
<td>$58</td>
<td>1</td>
<td>$58</td>
</tr>
<tr>
<td>Mice upkeep</td>
<td>$0.35/cage/day</td>
<td>6 cages/56 days</td>
<td>$117.60</td>
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<tr>
<td>Mouthpiece</td>
<td>$25/mouth guard</td>
<td>4</td>
<td>$100</td>
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<tr>
<td>Binder Poly(ethylene), oxidized</td>
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<td>Binder glycol 4000</td>
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<td>$64.89</td>
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**Total Budget:** $1895.46
Acknowledgements

- Dr. John Enderle, BME UConn
- David Price, BME UConn
- Dr. Shiva Kotha, BME UConn
- Dr. Martin Fox, ECE UConn
- Dr. Sunil Wadhwa, UCHC
- Tristan Ramas, BME UConn
References