Ultrasound Stimulation of Insulin Release from Pancreatic Beta Cells

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PURPOSE

Type 2 diabetes mellitus is a complex metabolic disease that has reached epidemic proportions in the United States and around the world. Controlling type 2 diabetes is often difficult. Many patients are poorly compliant with lifestyle change recommendations, and pharmacological management routinely requires complex therapy with multiple medications, and loses its effectiveness over time. Thus, new modes of therapy are needed that will target directly the underlying causes of abnormal glucose metabolism. The objective of this study is to explore a novel, non-pharmacological approach that utilizes the application of ultrasound (US) energy to augment insulin release from pancreatic β-cells.

THE COST OF DIABETES

- As of 2011, it is estimated that 25.8 million people have diabetes.
- The number of people diagnosed with diabetes has risen from 1.5 million in 1958 to 18.8 million in 2010, an increase of epidemic proportions.
- The American Diabetes Association released new research on March 6, 2013 estimating the total costs of diagnosed diabetes have risen to $245 billion in 2012 from $174 billion in 2007, when the cost was last examined.
- People with diagnosed diabetes incur average medical expenditures of about $13,700 per year, of which about $7,900 is attributed to diabetes.

SPECIFIC AIMS

- Determine effectiveness of ultrasound stimulation of insulin release from pancreatic β-cells.
  - ➢ In this aim, we test the effectiveness of low-intensity ultrasound at different parameters in stimulation of insulin release from pancreatic β-cells.
- Determine effects of ultrasound stimulation on viability of the pancreatic β-cells.
  - ➢ In this aim, we test the extent to which ultrasound stimulation affects viability of human pancreatic β-cells.
- Determine the range of pressures and temperatures to which the cells are exposed to during ultrasound treatment.
  - ➢ In this aim, we use a simulation software called PZFlex to model our experimental setup and create pressure maps of the applied ultrasound exposures. Temperatures inside the chamber are monitored experimentally with a thermocouple.

CELL SAMPLE ANALYSIS

- ***Quantification of Insulin Release:***
  - Insulin ELISA was used to measure the quantity of insulin released from ultrasound-exposed β-cells and their respective intracellular insulin content. Measurements were performed on samples collected before and after treatment. Measured values from ultrasound treated groups were compared to those obtained from sham groups.
- ***Cell Viability Studies:***
  - Cell viability was assessed in samples collected before and after ultrasound treatment using the trypan blue dye exclusion test. Measurements from ultrasound treated groups were compared to those obtained from sham groups.

METHODS AND MATERIALS

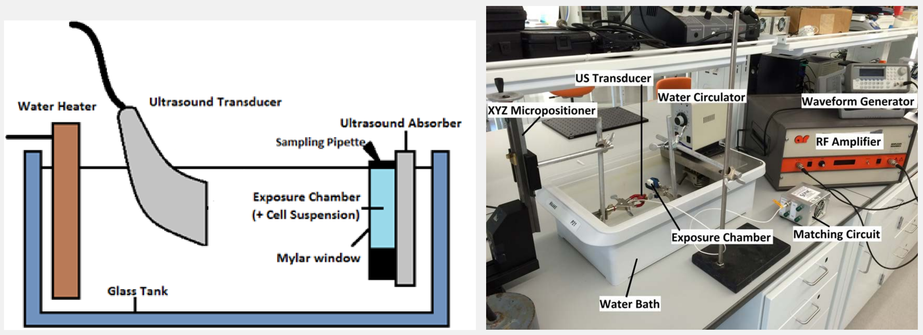

Fig. 1: Experimental setup for ultrasound stimulation of pancreatic β-cells

- A planar ultrasound transducer was used to sonicate the cells using a wide range of ultrasound parameters.
  - Frequencies: 400 k Hz, 600 kHz, 800 kHz, 1 MHz
  - Intensity: 1 W/cm^2
  - Duty cycle: 100% (continuous) for a duration of 5 minutes.
- INS-1 β-cells were placed and suspended in an exposure chamber made of polylactic acid (PLA) with acoustic transparent windows made of Mylar.
- The exposure chamber containing the cell suspension was filled with fluid and was placed at the acoustic focus of the transducer (d_{FF} distance).
- Cell samples (100 µL) were collected before ultrasound treatment (t = 0 min), 5 min after the start of the treatment and 30 min after the end of treatment.

PRESSURE MAPS & THERMAL MEASUREMENTS

- The experimental setup was modeled with PZFlex and pressure maps were generated for all ultrasound exposures to determine the range of pressures to which the cells are exposed to during treatment **(Fig. 2).**
- Material properties, parameters and dimensions were compiled from measurements and manufacturers' data.
- Temperature variations inside the exposure chamber were monitored throughout the ultrasound treatment by inserting a thermocouple in the chamber.
- In all cases, temperature inside the chamber increased by a maximum 2°C on average (**Fig. 3**).

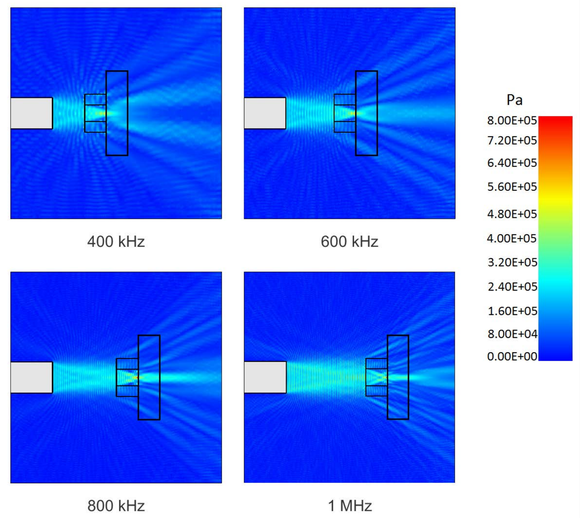

Fig. 2: Pressure maps of all ultrasound exposures generated with PZFlex modeling software

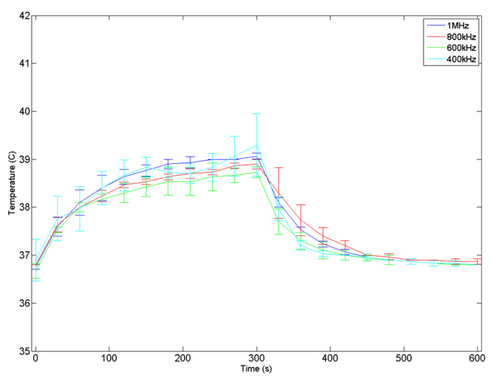

Fig. 3: Temperature variations inside the exposure chamber for all ultrasound exposures

RESULTS

- Our data indicated that application of therapeutic ultrasound can lead to safe increase of insulin secretion from β-cells at a frequency of 800 kHz and intensity of 1 W/cm^2.
- Cells exposed to 1 MHz ultrasound were also shown to remain viable, though no statistically significant increase in insulin release was observed.

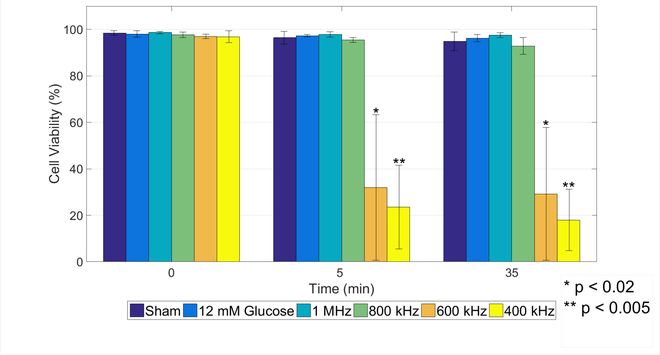

Fig. 4: Results (n=6) of cell viability after ultrasound treatment as measured by trypan blue dye exclusion test.

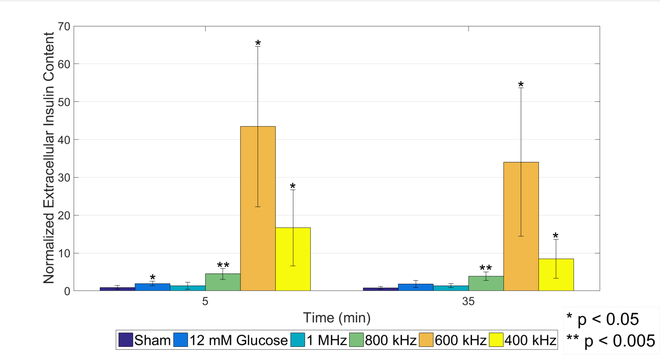

Fig. 5. Results (n=6) of insulin released into the extracellular space by β-cells exposed to ultrasound as measured by Insulin ELISA. Measured insulin values at t = 5 min and t = 35 min were normalized to initial values measured at t = 0 min.

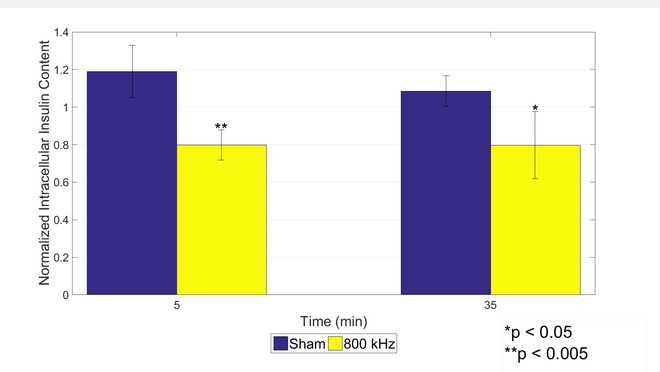

Fig. 6. Results (n=4) of intracellular insulin content in β-cells exposed to ultrasound as measured by Insulin ELISA. Measured insulin values at t = 5 min and t = 35 min were normalized to initial values measured at t = 0 min.

CONCLUSIONS AND FUTURE WORK

If proven successful our method may find a clinical application due to the non-invasive nature of therapeutic ultrasound treatment of human pancreas (through an appropriate acoustic window). Our future studies will focus on finding an optimal set ultrasound parameters for applications to the pancreas in an *in vivo* animal model, to determine whether it would be possible to stimulate β-cells without stimulating other endocrine and exocrine cells of the pancreas.

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