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# IMPLANTABLE MINIPUMP WITH MEMS ELECTROTHERMAL VALVE FOR BOLUS INJECTION IN MICE

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## ABSTRACT
An implantable, single-use miniature infusion pump (MIP) was designed to allow radiotracer injection and functional neuroimaging in freely moving mice. The pump comprises a pressurized reservoir, and a parylene electrothermal valve, which opens to inject tracer through an intravenous catheter into the circulation. A 3-layer 300 µl elastomeric reservoir was built by molding silicone in two-part metal casts. The valve was powered by inductive power transfer from an external 20 cm diameter primary coil to an implanted miniature 8-turn, 1.6 cm diameter Litz-wire secondary coil capable of generating 150 mW at the frequency of 2 MHz.

## INTRODUCTION
The MIP is an implantable, remotely activated micro bolus infusion pump designed for radiotracer injections in freely moving animals for functional neuroimaging applications (1). Developing the MIP as a tool for functional brain imaging in transgenic mouse models of human disease opens a new avenue of research in the area of 'imaging genetics' (2).

**Specific Aims:** The specific aims of the study for the manufacture and testing of a 4-gram mouse pump (10% of body weight of a 40 gram mouse) were as follows:
1. Design and characterize a miniaturized pressurized liquid reservoir.
2. Develop a single-use micro electromechanical systems (MEMS) parylene electrothermal valve for implantation in a 40-gram mouse.
3. Power an implanted mouse-size coil based on the power requirements of the electrothermal valve using inductive power from an electromagnetic field of an external resonating inductive coil driven by a class E oscillator.

## METHODS
The reservoir was constructed by combining three, two-part metal casts (top, middle and bottom layer) filled with medical grade Silicone. After filling, each cast was sealed and allowed to cure. The top layer consisted of a disk with an inverted dome and a central silicone nipple to accommodate needle puncture during loading of the reservoir. The middle layer is in the shape of a partial annulus with a V-shaped entry, which accommodates a 2-inch long piece of silastic tubing. A stiff mylar circle cut to fit inside the lip of the top piece was glued beneath the middle layer to prevent the needle of the loading syringe from puncturing through the reservoir. The circular bottom layer was used to leak proof the reservoir and served as the base of the unit (Fig. 1). After curing the three pieces were glued to each other with silicone glue. Once sealed, the elastomeric reservoir could be loaded with a pharmaceutical agent until released through the catheter and valve.

The MEMS electrothermal valve consisted of platinum heating element embedded in a flexible parylene C membrane (Fig. 2a). The normally closed valve was situated in between the mouse catheter and reservoir. Two contact pad flaps facilitated connection to the circuitry (Fig. 2b).
The valve opened when sufficient current was applied to the element to result in thermal degradation of the parylene/Pt membrane (Fig. 2c). This allowed rapid release of the tracer stored in the pressurized reservoir through the catheter into the venous circulation.
The current was generated by placing the secondary coil (8-turn Litz wire 12-strand, 41-gage, D=16 mm, f=2MHz, L=2.01 µH, C=3149 pF, Q=59) inside the electromagnetic field of a 20 cm diameter primary coil wrapped around the animal's cage (3).

 

**Fig. 1.** Mouse reservoir, From right to left: bottom, middle and top layer, the completed reservoir in comparison to a penny

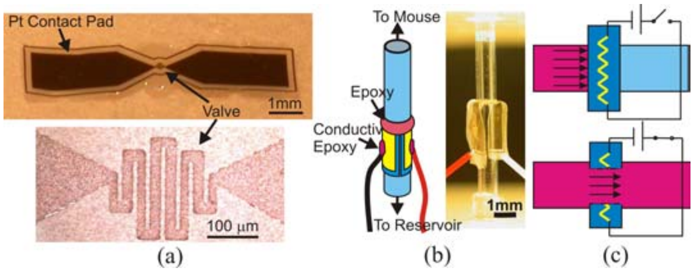


**Fig. 2.** MEMS parylene electrothermal valve: (a) Valve image, (b) Valve package, and (c) operation principle of the valve

**Bench top testing:**

1. Flow rate: The volume ejected per second was measured for three different reservoirs in three different trials. The reservoirs were filled with 300 µL distilled water by needle injection through the top of the reservoir. The amount of liquid discharge over a fixed period was measured to obtain the flow rate profile.
2. Leak test: Three reservoirs were clamped and filled to the maximum capacity and tested overnight for any possible leakage.

3. Valve test: The temperature to applied current relationship was obtained. The current and power required to open the valve were measured and optimized.

4. Optimization of the number of turns in the secondary coil: The optimal number of turns for the secondary coil that delivered sufficient power to activate the electrothermal valve was determined. For these tests the secondary coil was placed at the center and midplane of the primary coil.

## RESULTS

Three reservoirs produced the same linear flow profile indicating that the manufacturing process was reproducible (Fig. 3).

The bench top tests showed that the reservoirs were leak proof for up to ten punctures.

Valve characterization showed that the current applied to open the valve was 25-50 mW.

The 8-turn secondary coil could best generate the necessary power to activate the electrothermal valve.

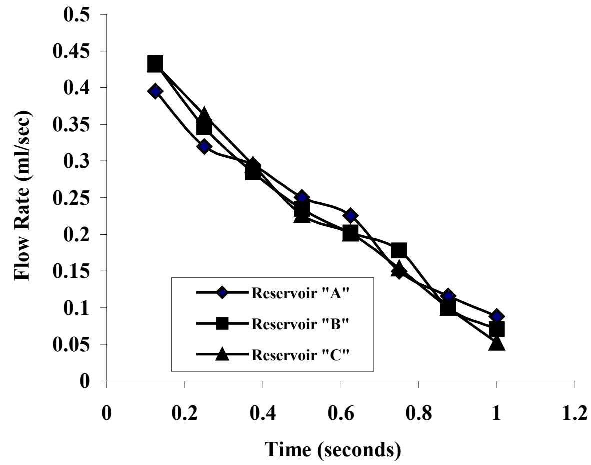


**Fig. 3.** Flow rate (average of 3 trials) for three different reservoirs

## CONCLUSION

The newly designed reservoir was optimized for implantation in a 40-gram mouse. The flow rate was found to be highly reproducible, while there was no indication of leaks up to 10 punctures. The design, fabrication, and bench top characterization of the disposable valve were completed. The valve can be operated with low current and power. Opening power of 25-50 mW was obtained. The induction power was sufficient to activate the electrothermal valve when the secondary coil was placed inside the electromagnetic field of the primary coil.

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