Developing a Wearable Device to Deliver Preferential Cooling to the Brain

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INTRODUCTION

Therapeutic hypothermia is a promising neuroprotective strategy following cardiac arrest, stroke, and epilepsy, as it can reduce ischemic brain damage and limit irreversible neuronal necrosis. However, current cooling methods often rely on whole-body hypothermia or bulky devices, which may cause complications such as shivering and poor portability.

Clinical studies have reported improved neurological outcomes and reduced mortality with controlled hypothermia treatment. By lowering brain temperature, hypothermia decreases cerebral metabolic demand, oxygen consumption, and inflammation, thereby protecting against ischemic injury. This project developed a localized, portable wearable cooling device through computational modeling and complementary physical prototyping.

DESIGN CONCEPT

To build the most realistic model for brain cooling, I first developed a software simulation in COMSOL Multiphysics. The Pennes bioheat equation (Eq. 1) was used to compute heat transfer within brain, skull, and skin layers during localized cooling. The simulation was used to predict temperature distributions, estimate achievable brain cooling capability, and compare theoretical results with physical prototype measurements.

$$\rho c \frac{\partial T}{\partial t} = k \, \Delta T + \rho_b c_b \omega_b \left(T_b - T \right) + E \qquad \text{Eq. 1}$$

To achieve fast and power efficient cooling while keeping portability high, I also designed a peltiers based cooling system shown in Figure 1B. Figure 1A showed the overall device schematic, where peltiers get power from power banks and reject heat through heatsinks.

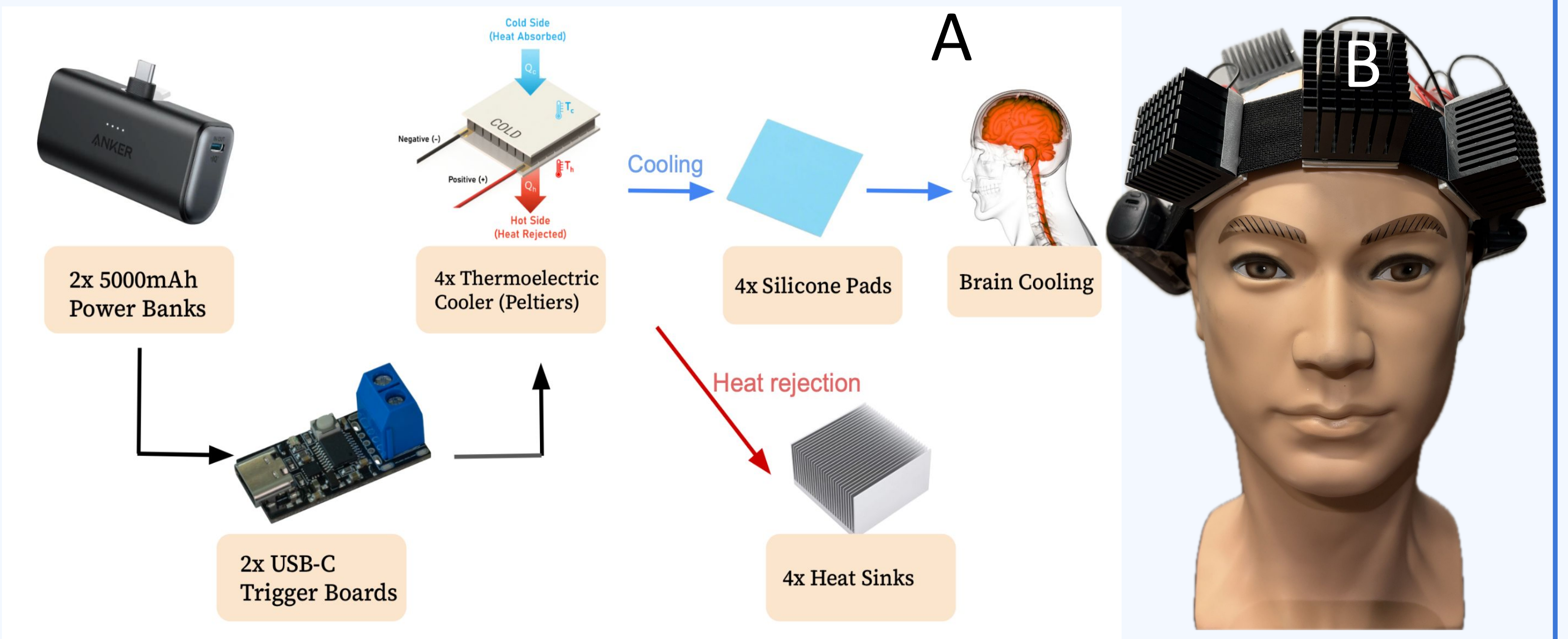

Figure 1: Brain Cooling Experimental Test System Schematic and Envisioned Use

RESULTS

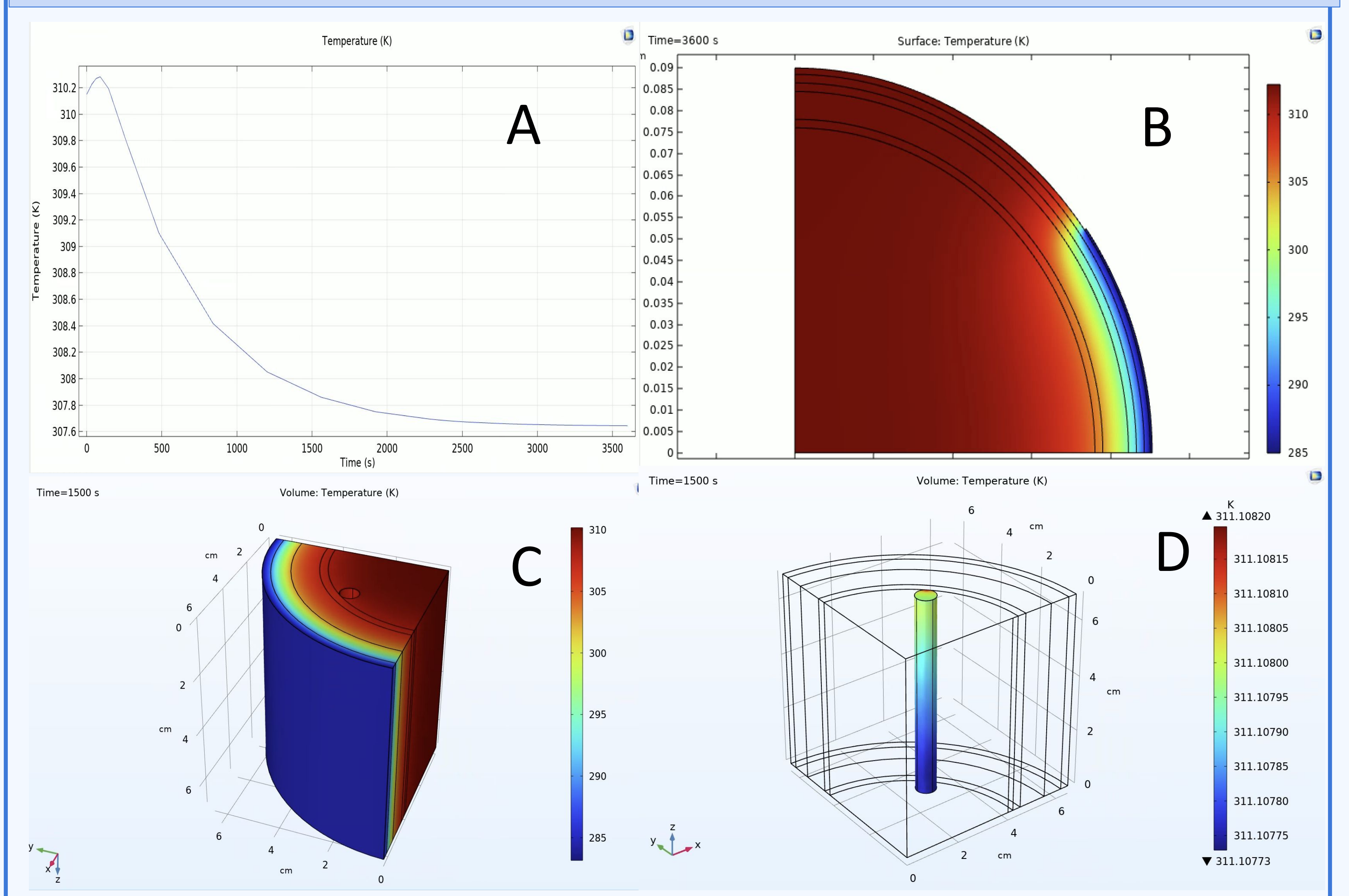

Figure 2: Temperatureover time plot in the brain from COMSOL simulation

Figure 2A shows the COMSOL solution of the average brain cortex temperature beneath the cooled region as a function of time. This temperature drops as the cooling duration increases and eventually settles at 307.6 °K. This reduction falls within the targeted mild hypothermia range (32-35 °C) associated with therapeutic hypothermia. Figure 2 B shows a temperature map at the sagittal cross section of the head, blue areas are where the peltiers are placed, which results in a significant amount of cooling.

Figure 2C and 2D showed how much neck cooling can decrease the arterial blood temperature as it travels into the brain. My simulation shows the cooling on the blood stream is insignificant (<0.1 °C) due to high flow rate, therefore this approach is not implemented in our final prototype.

At the same time, my partner Meaghan constructed a physical brain blood flow architecture so we can put our physical prototype into test.

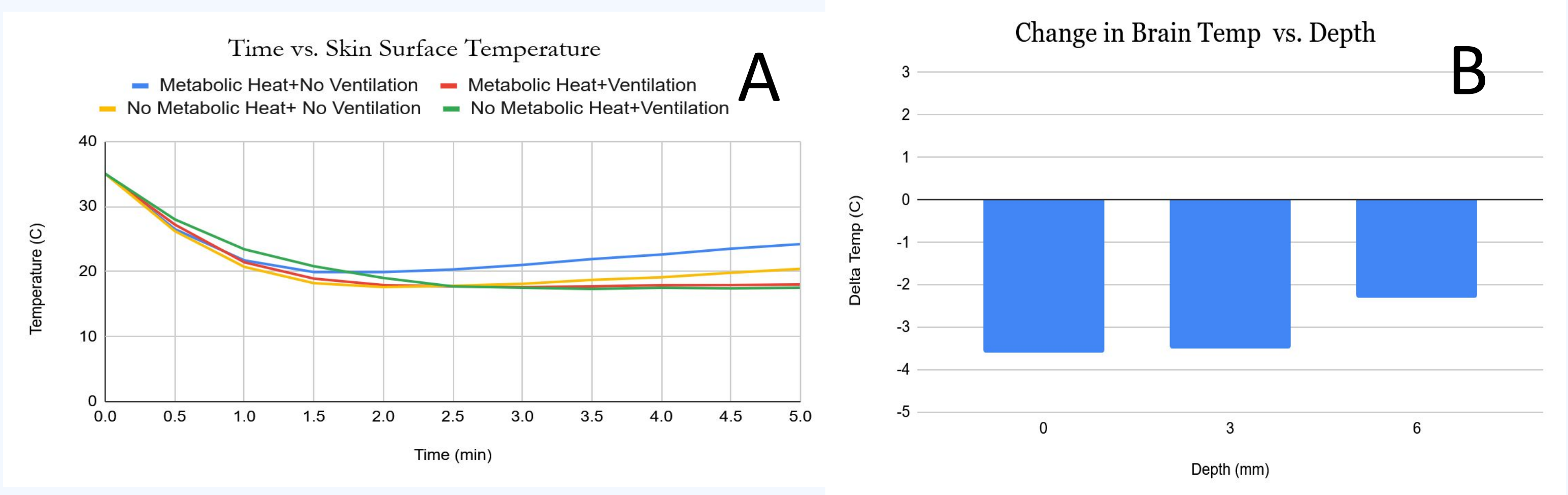

Figure 3: Change in brain temperature over time from physical experiment

RESULTS

After closely working with Meaghan for our experimental setup and data collection, we obtained the results shown in figure 3C and 3D. Figure 3C shows physical testing was conducted under various ambient conditions, including fan-assisted heat sink and a heated water reservoir. Our data showed skin surface temperature decreased rapidly until stabilizing after 1.5 minutes cooling to 17-19 °C when ventilation is present. Figure 3D shows this translates to 3.6 °C cooling at the surface of the brain and 2.3 °C at 6mm down. The limitation of the physical experiment is that it did not take into account the full extent of blood perfusion and heat generation. Nevertheless, the results showed the cooling is likely present in all of the grey matter (~3mm) where most of the neurons lie.

CONCLUSIONS AND FUTURE DIRECTIONS

The key results collected from computational modeling and physical experiment demonstrated the device is indeed capable of achieving sustained 2-3 °C cooling in the cortical gray matter region of the brain. However, a current limitation of this design is that the cooling area is restricted by the fixed placement and surface area of the Peltier modules. Future improvements may include a system with repositionable cooling elements to target patient-specific regions, or distribute full-head cooling to increase coverage. Such advancements could improve treatment flexibility, personalization, and overall device effectiveness.

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