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Temperature decrease in the brain from a Slush Puppie

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Abstract
This paper investigates the temperature decrease of the blood in the brain as a consequence of drinking an entire serving of Slush Puppie (236.6 ml) in one sitting. Due to the limitations of the size of the mouth, the complete consumption was achieved with 3 mouthfuls. The final temperature of the blood in the brain was calculated using heat transfer equations, assuming thermal equilibrium is established, and was found to equal 36.37 ℃, a temperature decrease of 0.63 ℃. In order for significant damage to be done to the brain, more than 3 Slush Puppies must be consumed.

Introduction
Often on a warm day after drinking or eating a cold food such as a Slush Puppie, a sudden sharp headache is experienced; known as brain freeze. Brain freeze is the result of the cold substance coming into contact with the back of the palate at the juncture of the internal carotid artery and the anterior cerebral artery and drastically reducing the blood temperature [1]. The reduction in temperature is due to heat transfer between the palette and the cold liquid. The internal carotid artery feeds the brain with blood, and the anterior carotid is where the brain tissue starts [1]. A reduction in temperature at this junction causes a nerve response: blood vessels constrict, restricting blood flow to the brain and hence causing headaches.

Drinking small amounts of cold drinks can lead to this effect. This paper evaluates the consequence of consuming a large volume of iced drink in one go. The drink that will be used as a reference will be a Slush Puppie, and a standard single serving of 236.6ml [2] will be consumed. The resulting temperature that the blood in the brain is reduced to will be calculated, using thermal energy equations.

Calculation
Although the standard size of a Slush Puppie is 236.6 ml, the average volume of liquid that a man can fit into his mouth at a given time is approximately 85 ml [3]. Therefore, approximately three mouthfuls would be needed to consume the entirety of the Slush Puppie.

During each mouthful, heat transfer occurs between the blood, the bone in the palate of the mouth, and the Slush Puppie. It is assumed that the transfer of heat energy is uniform through the liquid and palate to the blood. The Slush Puppie is assumed to be in the mouth long enough for thermal equilibrium to be established between the palate, the liquid, and the blood. When this equilibrium is achieved, the liquid is swallowed, and the next mouthful immediately replaces it. This process repeats until the total volume of the Slush Puppie has been consumed.

For simplicity, this model assumes there is heat transfer between the liquid and palatal bone, and then from the bone to blood in the brain. The model does not account for energy loss from the system, or the reduction in the temperature gradient as blood travels from the palate to the brain in these blood vessels. Further, the model does not consider that, due to the constant movement of blood, there is never complete equilibrium of blood temperature.

In order to calculate the temperature after the heat exchange between the Slush Puppie, the palate and the blood in the brain, a rearranged version of the energy transfer equation, equation 1 [4], is used.

$$Q = mc\Delta T. \quad (1)$$

Where Q is equal to the energy, m is equal to the mass, c is equal to the specific heat capacity and ΔT is the change in temperature.

When two mediums are in contact with each other, the amount of energy transfer will eventually reach a point of equilibrium, equation 2 [4].

$$Q_{in} = Q_{out} = m_1 c_1 \Delta T_1 = m_2 c_2 \Delta T_2. \quad (2)$$

Rearranging equation 2 for the final temperature, T_f, gives equation 3 [4].

$$T_f = \frac{m_1 c_1 T_1 + m_2 c_2 T_2}{m_1 c_1 + m_2 c_2}. \quad (3)$$

Where T_1 and T_2 are the initial temperatures for the first medium and the second medium respectively. The average temperature of the blood and palate is 37 ℃ [5], and the Slush Puppie will be assumed to have a temperature of 0 °C. The specific heat capacity is 3.49 $kJkg^{-1}{}^{o}C^{-1}$ for blood [6], and 4.18 $kJkg^{-1}{}^{o}C^{-1}$ for the Slush Puppie, assuming it is made of water. The palate is assumed to be made of bone and so the specific heat capacity is 0.44 $kJkg^{-1}{}^{o}C^{-1}$ [7]. The masses required for equation 3 were worked out using equation 4 [4].

$$m = \rho V. \quad (4)$$

Where ρ is the density of the liquids and V is the volume. The density of blood is 1060 kgm^{-3} [8], the density of bone, for the palate, is 1900 kgm^{-3} [9] and the density of the Slush Puppie was assumed to be the same as water, 1000 kgm^{-3}, so the flavourings and additives are not considered. The volume of blood in the brain is 150 ml, assuming an average man of 150 pounds [10]. The volume of Slush Puppie where heat transfer could take place was calculated using the surface area of the palate and the thickness of the layer of liquid that was involved in the heat transfer. The mean palate size is 20.1 cm^2 [11], and the thickness of the layer is assumed to be 1 cm, meaning that the volume of Slush Puppie used in the calculations is 20.1 cm^3. The volume of the palate bone was calculated to be 1.15×10^{-5} m^3, using the palate size and average thickness of the deep palate midline, 5.71 mm [12].

These numbers were substituted into equation 4 and the mass for the blood was found to equal 0.159 kg, the mass of the Slush Puppie was equal to 0.021 kg and the mass of bone in the palate was equal to 0.022 kg.

All these values were substituted into equation 3, and the temperature was first calculated, for equilibrium between the Slush Puppie and bone. The bone temperature was then used to calculate the final temperature of the blood. These values were then used as initial temperatures for subsequent calculations. The initial temperature of the Slush Puppie remained as 0 ℃. The results for all 3 mouthfuls are shown in table 1.

	Temperature of palate bone	**Temperature of blood**
Initial Temperature	37℃	37℃
Temperature after 1st mouthful (85 ml)	3.67℃	36.40℃
Temperature after 2nd mouthful (85 ml)	0.37℃	36.47℃
Temperature after 3rd mouthful (66.6 ml)	0.036℃	36.37℃
Total reduction in temperature	36.96℃	0.63℃

Table 1 – The final temperatures at equilibrium, for each mouthful, up to 236.6 ml of liquid.

The final temperature of blood in the brain is 36.37 ℃, giving a total reduction in temperature of 0.63 ˚C. The palate bone decreases to a temperature of 36.96 ℃ and so can be seen to act as an insulator for the blood in the brain. The body functions at an optimum temperature of approximately 37 ℃. If the temperature drops below 35 ℃, the body will then be under hypothermic shock, leading to organ and respiratory failure if left untreated [13]. Using the blood temperature decrease from drinking one Slush Puppie, for the temperature to drop to 35 ℃, approximately 3 slushies would need to be consumed.

Conclusion

It was found that if an entire serving of Slush Puppie was consumed in one sitting, divided into three mouthfuls, the temperature of the blood in the brain would be reduced by 0.63 ℃ to 36.37 ℃. This was calculated using a rearranged heat transfer equation, based on thermal equilibrium. This small decrease in internal temperature is unlikely to be detrimental to the brain. However, if more than 3 slushies were consumed consecutively, the blood around the brain would be decreased by enough to cause damage.

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