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Does Anna Have a Frozen Heart?

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Abstract
In *Frozen*, Princess Anna freezes into a solid block of ice and comes back to life unharmed. This article explores how hypothermia impacts the body and the symptoms Anna faced that were not shown in the film. Modelling Anna's mean body temperature shows the likelihood of her surviving at such low temperatures in a non-fiction setting would be quite slim.

Introduction
In Disney's animated motion picture *Frozen*, Princess Anna is slowly frozen until her body is fully encapsulated by ice [1]. In a typical fairy tale ending, her sister Queen Elsa is able to unfreeze Anna's body through the power of love. After watching this film one is left to wonder if the physiological effects of this freezing process would have led to Anna's death.

Hypothermia
Cold is generally defined as an environment that can lead to rapid heat loss from the body [2]. Duration, temperature, and length of exposure all alter the physiological responses to cold. Cold stress can result in dangerous medical conditions such as hypothermia and frostbite [2,3]. The kinetics and chemistry of the human body are optimized at 37°C [2]. The reduction of internal body temperature to 35°C, a hypothermic state, alters the physiology of the entire body [4]. During this 2°C reduction of temperature the body increases the metabolic rate to compensate for heat loss, reduces blood flow to the skin through vasoconstriction, and begins shivering [2]. Once hypothermia begins there is a linear reduction in heart rate, cardiac output, and muscle contraction. The decreases in metabolism and CO2 production cause reduced cerebral blood flow leading to loss of consciousness around 30-26°C [2]. At 20°C the body falls into cardiac arrest; however, if rewarming occurs individuals can still survive [2].

Would Anna Survive the Freezing?
Many physical characteristics and external factors need to be considered when determining the likelihood of surviving hypothermia. Therefore, both the setting of *Frozen* and Anna's characteristics must be analyzed before determining her fate. It can be assumed that Anna's average core temperature before freezing is the average human core temperature, 37°C [5]. If Anna were to endure fatal hypothermia, her internal body temperature would have to drop to 24°C or below [3]. In the film, Anna slowly freezes. For calculation purposes it was assumed this environment is analogous to a vat of ice water.

Water freezes at 0°C, and therefore it can be assumed that the external environment Anna is in is 0°C. In cold weather human skin can range from 29°C - 33°C, considering sweating regulation and the use of protective clothing [6]. Therefore it is reasonable to assume that the initial temperature of Anna's skin is the average of this range, 31°C. The freezing rate of skin must also be considered. It has been suggested that the constant freezing of animal skin at 0°C causes a decrease in skin temperature at a rate of 0.5°C/minute [7]. The time it takes for Anna's skin to reach 5°C must be determined since this temperature indicates the beginning of fatal hypothermia [6]. To determine the amount of time it will take for Anna's skin to reach 5°C, one must consider the difference of Anna's initial skin temperature (31°C) and her final skin temperature (5°C), which is 26°C. The aforementioned rate can be

used to calculate the length of time it takes Anna's skin to reach 5°C.

$$26^oC \times \frac{1\ minute}{0.5^oC} = 52\ minutes$$

Therefore, it would take 52 minutes for Anna's skin to reach 5°C. In the film the process of encapsulating Anna in ice takes approximately 1 minute and 45 seconds [1]. However, the entirety of the freezing process takes place over a much larger portion of the film in which the passage of time is unclear therefore subsequent calculations assume that her freezing is constant over 52 minutes.

A simple way to determine the temperature of the average tissue in the body is by calculating the mean body temperature (MBT) [8]. The MBT is the mass-weighted average temperature of the body tissue found in the torso [8]. The equation that models this temperature is as follows [8]:

$$MBT = 0.64T_{core} + 0.36T_{skin} \qquad (1)$$

where T_{core} is the core temperature and T_{skin} is the skin temperature. Assuming Anna's core temperature is 24°C and her skin is 5°C after 52 minutes, her MBT would be 17.16°C, which is well under the average MBT of 34°C [8].

According to these results, Anna will experience fatal hypothermia if she is exposed to an external environment analogous to 0°C ice water for 52 minutes. In this time, her MBT will decrease to 17.16°C. One of the lowest reported core body temperature of a hypothermia survivor was 18°C [2]. Thus, it is very unlikely Anna would have survived the freezing shown in the film.

Conclusion

If Anna is subjected to the constant freezing described above the likelihood of her survival is slim. Her MBT would decrease to 17.16°C if her skin decreased to 5°C over a total time of 52 minutes. This is below the lowest core body temperature recorded to have survived hypothermia [2]. The film also failed to demonstrate the key physiological effects associated with freezing and hypothermia. Downplay of the seriousness of hypothermia has lead to a motion picture that has warmed the hearts of millions.

References

[1] *Frozen* (2013) Walt Disney Studios Motion Pictures, (film).
[2] Parsons, K. (2014), *Human thermal environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance* (CRC Press), 3, 355-28
[3] Brown, D.J.A., Brugger, H., Boyd, J. & Pall, P. (2012) *Accidental Hypothermia*. The New England Journal of Medicine 370.20, 1930-1938.
[4] Wood, T., & Thoresen, M. (2014), *Physiological responses to hypothermia*. Seminars in Fetal & Neonatal Medicine 1-10.
[5] Kushimoto, S., et al. (2014), *Body temperature abnormalities in non-neurologial critically ill patients: a review of the literature*. Journal of Intensive Care 2.1 14-15.
[6] Benzinger, T.H. (1961), *The diminution of thermoregulatory sweating during cold-reception at the skin*, Proceedings of the National Academy of Science of the United States of America, 4., 1683-1688.
[7] Gage, A. (1979), *What temperature is lethal for cells?* The Journal of Dermatologic Surgery and Oncology 5. 6 459-460.
[8] Lenhardt, R., & Sessler, D.I. (2006), *Estimation of mean body temperature from mean skin and core temperature*. Anesthesiology 105.6 1117-1