Journal of Interdisciplinary Science Topics

Powers of Poison: The Science behind Sherlock

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04/04/2014

Abstract
In the popular BBC television series *Sherlock*, the villainous mastermind Moriarty commits a murder by introducing botulinum toxin to a victim's eczema cream. This paper examines the science behind this scenario and analysis indicates that it is feasible to commit murder in this manner but a longer timeframe than described in Sherlock is required.

Introduction
The BBC television program *Sherlock* is a modern-day adaptation of the famous book series by Sir Arthur Conan Doyle, which follows the adventures of the fictional detective Sherlock Holmes and his colleague Dr. John Watson. During the episode "The Great Game", Holmes must solve the murder of a child named Carl Powers. Holmes examines the victim's sneakers and finds traces of botulinum toxin, a deadly neurotoxin.

Carl Powers
The victim of the botulinum toxin was an 11 year old boy named Carl Powers. He was a champion swimmer from Sussex who was visiting London for a swimming competition when he mysteriously drowned. Powers was known to have eczema and the only evidence of the toxin was found in his shoes indicating that the toxin had been introduced through his eczema cream. Holmes deduces that Powers had applied the toxin-laced medication two hours prior to his swimming competition, at which point the poison took effect and paralysed his muscles, causing him to drown. The two-hour delay was inferred based on the time it would have taken for Powers to travel from his hometown of Sussex to his competition in London. Holmes guesses that the murderer, Moriarty, had strategically introduced the toxin right before Powers' swimming race, causing him to drown in the pool.

Absorption of Botulinum toxin
Botulinum toxin is a potent neurotoxin produced by the bacterium *Clostridium botulinum* [1]. Botulinum toxin cannot be absorbed through intact skin; however, it can enter the bloodstream through open wounds or lesions [2]. Powers had eczema, a noncontagious inflammatory skin disease that can result in lesions on the feet depending on severity [3]. He was likely diagnosed with atopic eczema, the most common type of the disease, which often occurs in children on various parts of the body, including the feet. Atopic eczema is commonly treated with creams such as topical steroids which can reduce symptoms if applied twice daily [4]. If Power's cream was laced with botulinum toxin and applied to areas affected by eczema, the toxin would be absorbed through the lesions in his skin.

According to Sherlock Holmes, Moriarty introduced botulinum toxin, perhaps obtained from contaminated foods, into Powers' eczema cream. A study examining the hazards of botulinum toxin in foods found that cheese inoculated with *Clostridium botulinum* and incubated for 26 days contained up to 200 units/mL [5]. One unit of botulinum toxin is equal to 0.4×10^{-9} g of the toxin [6]. Therefore:

$$Poison\ collected = 200 \times 0.4 = 80 ng/mL = 0.08 \mu g/mL$$

Suppose that the top 5 mL of the eczema cream was laced with 5 mL of toxin with a concentration of 0.08 μg/mL, then the concentration of poison in the eczema cream would be diluted by a factor of 2, resulting in a final concentration of 0.04 μL. Furthermore, assuming that 1.5 mL of cream will cover the feet and will be applied twice daily with 80% absorption:

$$Absorption/time = (Toxin\ in\ cream \times (Cream\ applied)/day) \times percent\ absorbed$$

$$Absorption/time = 0.04\ (\mu g)/mL \times 3mL/day \times 0.8 = 0.1 \mu g/day$$

Powers would have been absorbing 0.1 μg of botulinum toxin per day, or 0.05 μg every time he applied his eczema medication. The amount of botulinum toxin required to kill half of all exposed individuals, referred to as the median lethal dose, is estimated to be 0.1 μg for humans [1]. Therefore, only two applications of toxin-laced cream could have proven lethal for Powers. In addition, the effect of botulinum toxin peaks at four to seven days and can last for up to six months, so the effects of subsequent doses would have been cumulative [7,8].

Onset of Symptoms

Botulinum toxin acts on cholinergic synapses in the peripheral nervous system to induce paralysis, ultimately leading to death [1]. The neurotoxin requires 24-72 hours to disrupt synaptic activity, and therefore the first symptoms of botulism do not occur until at least a day after contact with the toxin [7]. Therefore, Holmes' deduction that the poison was administered two hours prior to Powers' death was incorrect. Moriarty could not have planned for the poison to take effect while Powers was in the pool, as the onset of paralysis can vary by up to 48 hours. However, Moriarty's timing may still have been strategic because the first symptoms of botulism, which include blurred vision and difficulty swallowing, could have been ignored in the excitement of the swimming competition.

Conclusion

These findings show that the murder of Carl Powers could have been executed by mixing botulinum toxin into his eczema cream, though the scenario could not have occurred exactly as described by Sherlock Holmes. Although botulinum toxin cannot be absorbed through intact skin, the skin on Powers' feet would have had lesions and open sores due to his eczema, which could have facilitated the introduction of botulinum toxin into his bloodstream. The amount of toxin absorbed in this way would be small, but the high toxicity of botulinum toxin means even a minute concentration of the toxin could induce paralysis. A predicted time frame of one to two days would have been necessary for an adequate amount of toxin to be absorbed, and the toxin would require an additional one to three days to take effect.

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