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How possible was Prometheus' punishment?

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Abstract

In this paper we discuss the feasibility of the regeneration of Prometheus' liver – would cells be able to regrow fast enough to allow Prometheus' liver to be eaten every day by an eagle? For this, a simple model is constructed that incorporates the eating habits of eagles – how much food they eat in a day – as well as the natural regeneration time of a human liver. Our calculations have shown that if Prometheus' liver was the only food source of the eagle (300 g consumed per day), it would take approximately 2 days for complete regeneration of the mass of Prometheus' liver, but that 160.5 g of the liver could be eaten each day by the eagle and still result in complete regeneration.

Background

The myth of Prometheus comes from the Ancient Greeks. In the myth, the Titan Prometheus fought alongside the Gods against the rest of the Titans [1]. Zeus, king of the Gods, repaid the Titan by allowing him to create humans. Prometheus created the first humans in the image of the Gods, but he and Zeus disagreed on how important the humans should be. Zeus denied fire to the creatures of the Earth, and so Prometheus climbed up Mt. Olympus and stole fire from the Gods to give to people. When Zeus realised what he had done, he chained Prometheus to the side of a cliff, where every day his liver would be eaten by an eagle, and subsequently regrow overnight to be eaten again the next day [1].

In order to verify the feasibility of this myth, the eating habits of eagles, and the regeneration time of the human liver are considered.

Eagles

Due to the presence of Golden Eagles in modern-day Greece, it is possible to use this species as a model when investigating the myth [2]. Golden Eagles are large birds of prey that tend to feed on smaller mammals, birds, and reptiles, and sometimes larger carrion. They typically require around 250–450 g of food in order to sustain themselves daily, but are able to eat up to 900 g in a day and store it in a crop in their oesophagus for later [3].



Figure 1 – Prometheus bound by Peter Paul Rubens. Image from [4].

We have assumed that the eagle would not try to remove Prometheus' liver, and would instead treat him as though he were carrion and take bites. This is due to the eagle consuming Prometheus' liver as a punishment rather than as a method of survival.

The Liver

In this paper, Prometheus' liver will be assumed to be human sized, based on the proportions shown in

figure 1. In a typical human male, the liver weighs roughly 1.5 kg [5], and has an approximate volume of 4 m³ [6]. One remarkable feature of the liver is that it contains many hepatocyte cells, enabling the organ to regenerate after injury [7, 8]. This involves restoring both the mass of the liver, and any lost bodily functions.

The liver is able to regenerate so well due to the presence of numerous signal chemicals, such as hepatocyte growth factor, interleukin-6, and tumour necrosis factor α , which are sensed by the remaining hepatocyte cells. These stimulate rapid cell growth and mitosis to restore the initial mass of the liver [8]. Generally, other cell types within the liver do not divide in order to restore their original numbers until the majority of the mass is reformed.

The maximum amount of the liver that is able to be removed and yet still result in full mass and functional regeneration is 75 % of the initial mass. Studies have been done to show that the full regeneration of the mass takes 1 week in mammals, provided that any remaining lobes of the liver are intact [8]. In our model only the mass regeneration time of the liver is considered, as the ability of the liver to function normally is not a requirement for the eagle to eat it daily.

Calculations

From artistic interpretations of the myth (figure 1), Prometheus is depicted as human sized, and so a human-sized liver can be used in the model. Assuming that the eagle eats only 300 g of a liver per day, this is about 20 % of the total mass of the liver. From studies, we know that it takes 1 week, or 168 hours ($time_1$), for 75 % ($percentage_1$) of the mass of the liver to regenerate. Assuming a constant rate of regeneration, the time taken for 20 % ($percentage_2$) of the liver to regenerate can be calculated ($time_2$):

$$\frac{percentage_1}{time_1} = \frac{percentage_2}{time_2}$$

$$time_2 = \frac{percentage_2 \times time_1}{percentage_1}$$

$$time_2 = \frac{20\% \times 168\text{ hours}}{75\%} = 44.8\text{ hours}$$

This is longer than the regeneration time stated by the myth, which should be, at most, 24 hours.

However, if we consider that the eagle may not be eating Prometheus' liver purely to survive, we can calculate how much of a liver could be eaten and regenerated in a single day (24 hours):

$$\frac{percentage_1}{time_1} = \frac{percentage_2}{time_2}$$

$$percentage_2 = \frac{percentage_1 \times time_2}{time_1}$$

$$percentage_2 = \frac{24\text{ hours} \times 75\%}{168\text{ hours}} = 10.7\%$$

From these calculations, 10.7 % of liver could be consumed by the eagle per day whilst allowing total regenerate the mass entirely for the next day. This is equivalent to 160.5 g of a 1.5 kg liver, as used in this model.

Problems

There are various problems that arise when considering this myth: for the regeneration of the liver, at least 2 of the lobes must remain intact, which is unlikely to happen without careful dissection [8]. When carrion is present, it is generally not a single eagle that feeds from the carcass, but instead many [9]. This would be detrimental to Prometheus' ability to regenerate his liver, as a higher percentage of the liver would be eaten, and so it would be unable to regenerate fast enough. As Prometheus was chained to a cliff [1], he was therefore unlikely to be able to eat much. The regeneration of that number of cells would likely require lots of energy, and so the lack of sustenance of Prometheus would likely affect the rate of regeneration. The rate of regeneration is also unlikely to be linear across the whole week-long duration of the study, and so the assumption of the time for 20 % of the liver to regenerate is likely longer than used in the calculation.

Conclusion

This myth is not feasible due to the eagle's dietary requirements outpacing the regeneration of Prometheus' liver by a factor of 2 – Prometheus would be able to regenerate 300g of liver in 44.8 hours, but by that time the eagle would have returned to eat more. If the eagle is only eating Prometheus' liver in order to torment him for 30,000 years, then it could consume 10.7 % (160.5 g) daily before allowing it to regrow by the next day.

References

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