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A5 3 An estimation of human size limitations

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Abstract

In this paper, we explored the maximum possible size of a human based on their heat generation and dissipation capabilities when scaled up in height. According to our simplified analysis, the largest theoretical human could be 12.5 m tall and weigh 28 tonnes. However, this calculation does not consider other biological constraints such as bone density and cardiovascular function.

Introduction

The average human is around 1.7 m tall [1] but people can grow significantly taller. The size of life is regulated by many different factors as life has evolved to adapt to its environment. In our paper, we investigate (in a simplified fashion) the maximum size a human can grow to by looking at one of these factors, thermoregulation.

Theory

Out of the ways the human body can dissipate heat, perspiration is by far the most effective [2]. In our calculations, we only considered the rate of perspiration and assumed it to be constant with respect to internal temperature. We compared daily heat loss by perspiration with heat generated by metabolism as height increased to find the limit where heat can not be dissipated for a reference human. We kept the tri-ponderal mass index of the human constant so the height and mass scale in a $mass/height^3$ relation. The starting point was a reference unisexual adult of height 1.7 m, mass 70 kg [1] and age 30. The height was increased in small 1 cm increments.

Humans release about 75% of their metabolic energy as heat [2]. The total metabolic energy released in a day is called the rest metabolic rate (RMR) and is calculated by multiplying the basal metabolic rate (BMR), or the minimum amount of energy required to be alive per day, by a physical activity coefficient (PAL) [3]. For the BMR we used an average of both genders for the Mifflin-St Jeor equations [4] giving us:

$$BMR = 9.99 \times \text{mass (kg)} + 6.25 \times \text{height (m)} - 4.92 \times \text{age (yr)} - 83 \quad (1)$$

We then chose a PAL of 1.55 which reflects a sedentary lifestyle to help delay overheating as the human is scaled up, as heat generated increases with activity level. Multiplying Equation 1 by the 1.55 PAL and 0.75 for the efficiency gives the fraction of the RMR released as heat in terms of mass, height and age. This is what was modelled with the increasing height.

To find the heat dissipated we used the data from Taylor & Machado-Moreira [1] to calculate a daily perspiration rate of 10.5 L day^{-1} for the initial model human. As humans grow taller, their body surface area (BSA) increases, leading to a higher daily perspiration rate per m^2

of BSA. This was found for the model human, using the Mosteller BSA formula in Equation 2, to be 1.807 m^2 which gives an equivalent daily perspiration rate of 5.832 L per m^2. The latent heat of vaporization of sweat is 2426 J per gram of sweat at 30 which is equivalent to 2.426 MJ per litre as sweat is 99% water [2]. From this, we found the heat dissipated in a day through perspiration to be 14.148 MJ per m^2 of BSA. This assumes 100% evaporation and favourable air humidity and temperature conditions. Multiplying the BSA formula in Equation 2 by 14.148 MJ gives the heat lost in terms of height and mass. This is what was modelled with increasing height and compared to the heat generated.

$$BSA = \sqrt{mass \times height/3600} \tag{2}$$

Results and Discussion

In Fig. 1, the intersection- the point where more heat is generated than dissipated- occurs at a height of 12.52 m with a corresponding weight of 27961 kg, calculated from the TMI. Other than being unprecedented this is unfeasible for a variety of reasons. The linear perspiration rate assumed here does not take into account that up until a certain height, the core temperatures would likely be stable and there would not be a need to dissipate heat at such a rate. Additionally, the perfect environmental conditions are assumed for perspiration so that 100% of the latent vaporisation energy can be removed from the body. Taking into account cardiovascular function or the square-cube law would lead to a considerably smaller result.

Conclusion

In conclusion, our model predicts that a human can reach a maximum height of 12.5 m and weight of 28 tonnes, which deviates significantly from historical data. However, this can be explained by the assumptions in the model. In reality, human size is regulated by many factors which are more significant. Taking these into consideration would likely have the results trend closer to the data.

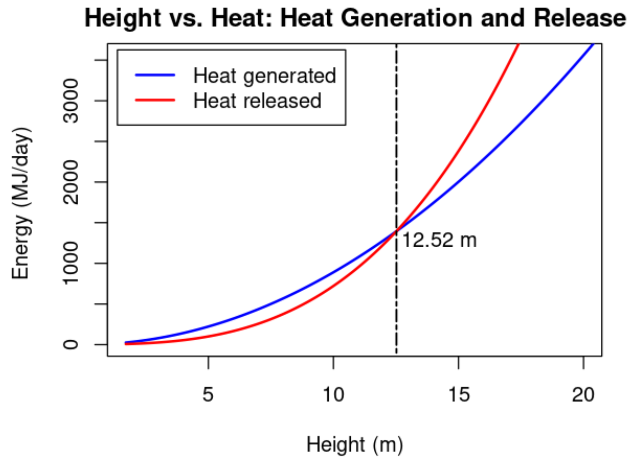

Figure 1: Plot of heat generated (red) and heat dissipated (blue) in a day with increasing height

References

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