The impact of oxyhemoglobin dissociation curve on oxygen distribution in heated biological tissue

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Summary

Oxygen distribution in biological tissue is influenced by temperature changes, which can alter tissue properties, affect perfusion, and disrupt oxygen delivery. This study uses numerical modeling to analyse how an external heat impulse impacts oxygen transport, with particular focus on the role of oxyhemoglobin dissociation curve (ODC) parameters.

The analysis integrates the Pennes bioheat equation with a Krogh cylinder-based oxygen transport model, through the relationship between blood velocity and tissue perfusion. Temperature elevation shifts the ODC to the right, while decreased capillary blood flow causes hypoxia. Lower pH levels correspond to higher oxygen partial pressure, whereas pCO_2 has a limited impact. These results underscore the complex interaction between thermal effects and oxygen transport mechanisms, providing insights into tissue response under varying physiological conditions.

Introduction

Oxygen deficiency in the body, clinically termed hypoxia, may result from alterations in temperature caused by factors such as physical exertion, illness, or external heat. Elevated temperature has shown to modify the properties of tissue, with the potential to cause thermal damage and thus disrupt the vasculature and oxygen delivery. Furthermore, temperature is one of the parameters (alongside pH, CO2, and 2,3-DPG) that can alter the shape of the oxygen dissociation curve (ODC).

The objective of the present study was to undertake a numerical analysis of the phenomena associated with alterations in oxygen distribution within biological tissue in response to an external heat impulse. In particular, the study focused on the effect of ODC parameters on tissue oxygen levels.

Methods

Thermal analysis is based on the Pennes bioheat transport equation, with tissue parameters being treated as temperature- or thermal-damage dependent. The thermal model is extended through the integration of an additional model based on the Krogh cylinder concept, which is employed to analyse alterations in the partial pressure of oxygen in the capillary vessel and surrounding tissue. The oxygen distribution model is linked to the thermal model via a relationship between blood velocity in the capillary and the perfusion coefficient.

Results and Discussion

It is evident that variations in oxygen partial pressure within the tissue due to elevated temperature can be readily identified, with the consequence that both tissue perfusion and capillary blood velocity are influenced. As the temperature rises, the oxyhemoglobin dissociation curve (ODC) shifts to the right, while a decrease in blood velocity leads to hypoxia. Additionally, the parameters of the haemoglobin dissociation curve influence oxygen distribution. Lower pH corresponds to a higher oxygen partial pressure. In contrast, the effect of pCO_2 on oxygen distribution appears to be relatively minor. However, it is important to acknowledge that CO_2 also impacts blood vessels and perfusion, which can indirectly influence oxygen transport. Depending on the conditions, this effect may be less pronounced compared to other factors such as blood flow and temperature.

Conclusions

An external heat impulse has an effect on biological tissue at various levels, resulting in changes to the thermophysical parameters of the tissue, particularly the perfusion coefficient. Furthermore, alterations are evident in the capillaries responsible for oxygen delivery to the tissue.

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