

THE THERMODYNAMIC MODEL OF MUSCLE TENSION

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Annotation: This article analyzes the thermodynamic model of muscle tension and its role in energy transformation and mechanical work generation. The study examines the processes of energy conversion into heat and mechanical work in muscle fibers and explores factors affecting their efficiency. In addition, the article discusses thermodynamic balance and fatigue-related issues in muscle activity.

Keyword: Muscle tension, thermodynamic model, energy exchange, muscle contraction, heat generation, biophysics, ATP breakdown, muscle fatigue, artificial muscle, biotechnology, physiology.

Аннотация: В данной статье рассматривается термодинамическая модель мышечного напряжения, её роль в процессах обмена энергией и преобразования её в механическую работу. Исследуются механизмы превращения энергии в тепло и механическое усилие в мышечных волокнах, а также факторы, влияющие на их эффективность. Кроме того, освещаются актуальные проблемы, связанные с термодинамическим равновесием и утомлением мышц.

Ключевые слова: Мышечное напряжение, термодинамическая модель, обмен энергией, сокращение мышцы, выделение тепла, биофизика, распад АТФ, утомление мышцы, искусственные мышцы, биотехнология, физиология

Annotatsiya: Ushbu maqolada mushak kuchlanishining termodinamik modeli, uning energiya almashinuvi va mexanik ish hosil bo'lishidagi roli tahlil qilinadi. Tadqiqotda mushak tolalarida energiyaning issiqlik va mexanik ishga aylanish jarayonlari hamda ularning samaradorligini oshirish omillari ko'rib chiqiladi. Shuningdek, mushak faoliyatining termodinamik muvozanati va charchoqlanish bilan bog'liq dolzarb muammolar yoritiladi.

Kalit so'zlar: Mushak kuchlanishi, termodinamik model, energiya almashinuvi, mushak qisqarishi, issiqlik hosil bo'lishi, biofizika, ATP parchalanishi, mushak charchoqlanishi, sun'iy mushak, biotexnologiya, fiziologiya.

The human body is a complex biological system in which all processes occur through energy exchange. Muscle tension is a clear example of energy exchange. The thermodynamic model of muscle tension studies the transformation of kinetic energy during the process of muscle contraction. This article analyzes some issues related to this topic, their causes, and possible solutions. These include the thermodynamic differences of individual muscle fibers and, one of today's most relevant topics, the thermodynamic adaptation of systems for artificial muscles and biotechnological models.

CORE Thermodynamic Differences of Individual Muscle Fibers – Muscle types are divided into fast-twitch and slow-twitch fibers, each differing in energy production, heat generation, and ATP consumption. These differences determine the fatigue rate, efficiency, and intensity of muscle fibers. The main issue is that the specific thermodynamic parameters for each muscle fiber type have not been fully studied.

Moreover, under real physiological conditions, different fiber types function together in a mixed form. Therefore, conducting thermodynamic analysis on individual fibers remains one of the most relevant challenges in modern biophysics and muscle physiology. Research shows that the thermodynamic differences among individual muscle fibers determine their energy efficiency, contraction mechanisms, and energy production processes.

There are several scientific approaches proposed to address these issues:

1. Determining specific thermodynamic parameters for each muscle fiber and conducting experiments based on muscle types — for example, using electromyography (EMG) and calorimetry to measure muscle tension levels and the amount of heat produced during muscle activity.
2. Developing a hybrid model, which integrates different types of muscles into a unified system for more accurate simulation.

Thermodynamic Adaptation for Artificial Muscles and Biotechnological Models – These are electromechanical systems designed to mimic the movement of natural muscles, commonly used in prosthetics and robotics. Thermodynamic adaptation refers to aligning artificial muscle characteristics — such as energy efficiency, tension, elongation, and contraction — as closely as possible to the biological properties of natural muscles.

In developing artificial muscles and biotechnological models, deeply studying and adapting the thermodynamic properties of natural muscles is a crucial factor. However, current artificial muscles still cannot fully replicate the energy efficiency of real biological muscles.

In the research “Morphology Modulation of Artificial Muscles by Thermodynamic–Twist Coupling,” the possibility of modifying the morphology of artificial muscle fibers through a thermodynamic twist-coupling strategy was explored. The main goal of this study was not only to ensure movement but also to enhance the ability of artificial muscles to adjust morphological parameters such as length, shape, and flexibility. This research serves as a successful example of applying a thermodynamic adaptation strategy to increase the potential of artificial muscles.

Due to the current limitations of thermodynamic models, the field of biotechnology is progressing relatively slowly. However, several scientific methods have been proposed to address these challenges:

1. Applying the energy conversion and production coefficients of biological muscles to artificial systems.
2. Developing efficient muscle prototypes and models based on nanomaterials and electrochemical reactions.

3. Establishing and expanding experimental facilities and laboratories that compare biological and artificial muscles.
4. Designing thermodynamic control systems — sensor networks that automatically analyze temperature, tension, and energy circulation in real time. These systems consist of temperature and tension sensors, microcontrollers, and control algorithms that continuously monitor and analyze energy flow.

Conclusion

The thermodynamic model of muscle tension provides a deeper understanding of energy exchange and heat generation processes during muscle activity. This approach makes it possible to analyze muscle efficiency, identify the causes of fatigue, and improve energy conservation. The model holds practical significance in sports, medicine, and biotechnology, offering both theoretical and applied insights into muscle function.

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