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МУНДАРИЖА – ОГЛАВЛЕНИЕ – CONTENTS

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GENERAL MORPHOFUNCTIONAL CHARACTERISTICS OF BONE TISSUE REGENERATION UNDER THE INFLUENCE OF EXTREME CLIMATIC FACTORS

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Abstract. *This article presents an analysis of existing scientific literature on the effects of extreme climatic factors on the process of bone tissue regeneration. The impact of abrupt temperature changes, hypoxia, humidity levels, ultraviolet radiation, and other extreme climatic factors on reparative osteogenesis is discussed. Data reported by various researchers on morphological remodeling of bone tissue, changes in cellular composition, blood supply, and functional characteristics associated with metabolic processes are summarized. In addition, the influence of extreme climatic conditions on osteoblast and osteoclast activity, collagen synthesis, and mineralization processes is analyzed. This literature review contributes to a deeper understanding of the mechanisms of bone regeneration and may serve as a scientific basis for future experimental and clinical studies.*

Keywords: *extreme climatic factors, bone tissue, regeneration, reparative osteogenesis, morphofunctional characteristics, osteoblasts, osteoclasts, hypoxia, temperature factor.*

KESKIN IQLIM OMILLARI TA'SIRIDA SUYAK TO'QIMASI REGENERATSIYASINING UMUMIY MORFOFUNKSIONAL XUSUSIYATLARI

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Annotatsiya. *Ushbu maqolada keskin iqlim omillarining suyak to'qimasi regeneratsiyasi jarayoniga ta'siri bo'yicha mavjud ilmiy adabiyotlar tahlil qilindi. Haroratning keskin o'zgarishi, gipoksiya, namlik darajasi, ultrabinafsha nurlanishi hamda boshqa ekstremal iqlim omillarining reparativ osteogenezga ta'siri yoritildi. Turli tadqiqotchilar tomonidan aniqlangan suyak to'qimasining morfologik qayta qurilishi, hujayraviy tarkibdagi o'zgarishlar, qon ta'minoti va metabolik jarayonlar bilan bog'liq funksional xususiyatlar umumlashtirildi. Shuningdek, osteoblast va osteoklast faolligi, kollagen sintezi hamda mineralizatsiya jarayonlariga keskin iqlim sharoitlarining ta'siri tahlil qilindi. Mazkur adabiyotlar sharhi suyak regeneratsiyasi mexanizmlarini chuqurroq tushunishga xizmat qiladi hamda kelgusidagi eksperimental va klinik tadqiqotlar uchun ilmiy asos bo'lib xizmat qilishi mumkin.*

Kalit so'zlar: *keskin iqlim omillari, suyak to'qimasi, regeneratsiya, reparativ osteogenez, morfofunksional xususiyatlar, osteoblastlar, osteoklastlar, gipoksiya, harorat omili*

ОБЩИЕ МОРФОФУНКЦИОНАЛЬНЫЕ ОСОБЕННОСТИ РЕГЕНЕРАЦИИ КОСТНОЙ ТКАНИ ПОД ВЛИЯНИЕМ ЭКСТРЕМАЛЬНЫХ КЛИМАТИЧЕСКИХ ФАКТОРОВ

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Аннотация. *В данной статье проведён анализ существующей научной литературы, посвящённой влиянию экстремальных климатических факторов на процессы регенерации костной ткани. Освещено воздействие резких температурных колебаний, гипоксии, уровня влажности, ультрафиолетового излучения и других экстремальных климатических факторов на репаративный остеогенез. Обобщены данные различных исследователей о морфологической перестройке костной ткани, изменениях клеточного состава, кровоснабжения и функциональных характеристиках, связанных с метаболическими процессами. Кроме того, проанализировано влияние экстремальных климатических условий на*

активность остеобластов и остеокластов, синтез коллагена и процессы минерализации. Настоящий обзор литературы способствует более глубокому пониманию механизмов регенерации костной ткани и может служить научной основой для дальнейших экспериментальных и клинических исследований.

Ключевые слова: *экстремальные климатические факторы, костная ткань, регенерация, репаративный остеогенез, морфофункциональные особенности, остеобласты, остеокласты, гипоксия, температурный фактор.*

Relevance of the topic. Bone tissue regeneration is one of the main tasks of modern medicine, which means the preservation of the physiological and morphological integrity of the bone, as well as the possibility of restoring disorders caused by pathological processes (fractures, defects, resections). The regeneration process is divided into natural (physiological) and pathological forms. Physiological regeneration provides continuous renewal of bone tissue, while pathological regeneration ensures its recovery after mechanical or ischemic damage.

Bone regeneration is the integral result of complex processes at its tissue, cellular, and molecular levels. These processes are ensured by adequate blood supply, the presence of healthy mesenchymal tumor cells, and the balanced action of cytokines and morphogenic proteins.

In recent years, ideas about the main mechanisms of bone regeneration have been theoretically substantiated. It has been established that bone tissue regeneration consists of several stages, which interact with each other and form a whole process. The first stage is the inflammatory phase, associated with the formation of a hematoma in the affected area, the release of inflammatory mediators, and the proliferation of leukocytes. The second stage is the formation of soft tissue callus (proliferative phase), during which mesenchymal tumor cells and fibroblasts proliferate very actively. In the third stage, chondroid tissue appears, after which it transforms into bone tissue (ossification). In the final stage, remodeling occurs, i.e., the formed bone tissue is reconstructed in accordance with mechanical loads. [1, 3, 5, 7].

Research objective. Indepth comparative and systematic analysis of existing scientific literature on morphofunctional changes in bone tissue regeneration under harsh climatic conditions, identification of current contradictory aspects, and determination of future research directions.

Modern morphological studies have shown that mesenchymal tumor cells (MTC) play a key role in bone regeneration. Growth factors (GF), transforming growth factors-beta (TGF-β), bone morphogenetic proteins (BMP), insulin-like growth factors (IGF), and others control the proliferation, differentiation, and migration of CFU. BMP proteins are particularly important in stimulating chondro- and osteogenesis [4, 6, 8].

Vascular structures are the main condition for the success of bone regeneration. The process of neovasculogenesis continues at all stages of regeneration. The new blood vessels deliver oxygen and nutrients to the regenerative calcium, as well as remove metabolites. Such factors as vascular endothelial growth factor (VEGF) and angiopoetin-1 promote neovasculogenesis, which in turn improves tissue oxygenation and trophism [2, 9, 10]. The mineral matrix of bone tissue (mainly hydroxyapatite) performs important functions in the regeneration process. It not only provides mechanical properties of the bone, but also acts as a depot for growth factors and cytokines. The mineralization process is associated with the activity of alkaline phosphatase (ALP), the production of osteocalcin, and other osteospecific markers [11, 12]. Temperature below normal (hypothermia) or above normal (hyperthermia) directly affects the activity of enzymatic processes that form the basis of bone metabolism. Under conditions of hypothermia, the main metabolism of the body slows down, the need for oxygen decreases, but cell proliferation and differentiation, which are necessary precisely for the reparative processes of bone tissue, also slows down. Experimental studies show that under hypothermia conditions, the proliferative activity of osteoblasts decreases, collagen synthesis is disrupted, and mineralization processes are delayed [13, 14]. Additionally, hypothermia leads to vascular spasm, disrupting microcirculation, resulting in tissue hypoxia [15, 16, 29, 30]. Climbing or diving leads to changes in atmospheric pressure, which affects partial oxygen pressure (pO2) in the blood and tissues. A certain degree of oxygenation is necessary for the normal physiological functioning of bone tissue. Under conditions of chronic hypoxia, HIF-1α (hypoxia response factor) is activated, which increases VEGF expression and stimulates angiogenesis. However, under conditions of severe hypoxia, aerobic glycolysis is limited due to oxygen deficiency, ATP production decreases, and cell death (apoptosis and necrosis) may increase. Chronic hypoxia in the bone can suppress osteogenesis, activate osteoclastogenesis, and reduce bone mineral density [17, 18]. Under conditions of acute hyperthermia, the morphological dynamics of regeneration processes differ significantly. Under the initial influence of heat stress, the inflammatory reaction can be more pronounced, as blood vessels dilate, vascular permeability increases, which increases the penetration of exudate and inflammatory cells.

However, due to the direct cytotoxic effect of heat, the function of inflammatory cells (neutrophils,

macrophages) can be disrupted, their phagocytic activity may decrease [19, 26, 28]. Hyperthermia in the proliferative phase can increase the mitogenetic activity of mesenchymal tumor cells, causing rapid growth of the callium. However, this rapid growth can be subtle: collagen sticks are irregularly positioned, and the composition of fibrous tissue may increase. Under conditions of hyperthermia, oxidative stress can develop more strongly, which can lead to lipid peroxidation of cell membranes, activation of proteolysis, and disruption of tissue proteoglycans of the matrix [20, 23, 24]. Hyperthermia during chondrogenesis can disrupt the differentiation of chondrocytes and the qualitative synthesis of the chondroid matrix. The ossification process can accelerate, but the crystallographic composition and mechanical properties of the mineral matrix can be disrupted. In general, under conditions of hyperthermia, regenerative callus develops rapidly, but its morphological structure and functional properties may differ from normal: inadequate mineralization of bone tissue, disruption of tissue architecture, and inadequate placement of ossificates can be observed [21, 22, 25].

Conclusion. Under conditions of sharp climate change, significant changes occur in the morphological state of bone regeneration, which depend on the nature of the climatic factor and the duration of exposure, manifested at all stages of regenerative processes. A complete study of these changes makes it possible to develop treatment tactics for bone injuries and fractures under the influence of climatic factors, as well as to optimize reparative processes and prevent pathological consequences.

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