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ПРИМЕНЕНИЕ ТЕХНОЛОГИИ 3D-БИОПРИНТИНГА В РЕКОНСТРУКТИВНОЙ ХИРУРГИИ ПОСЛЕОЖОГОВЫХ ДЕФЕКТОВ ВЕК

Аннотация: В данной работе рассматриваются клинические проблемы, связанные с послеожоговыми деформациями век, и оценивается потенциал технологии 3D-биопечати как инновационного решения для реконструкции. Традиционные хирургические методы часто сталкиваются с ограничениями, такими как осложнения в донорских участках, недостаточная совместимость тканей и неудовлетворительные эстетические результаты. 3D-биопечать предлагает индивидуализированные, биосовместимые и функционально интегрированные тканевые заменители. В статье анализируются последние экспериментальные и доклинические исследования, освещаются компоненты биочернил, типы клеток и конструкции скаффолдов, применимые к периорбитальной реконструкции.

Ключевые слова: 3D-биопечать, ожоги век, реконструктивная хирургия, регенеративная медицина, биочернила, тканевая инженерия, мезенхимальные стволовые клетки

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APPLICATION OF 3D BIOPRINTING TECHNOLOGY IN THE RECONSTRUCTIVE SURGERY OF POST-BURN EYELID DEFECTS

Abstract. This paper explores the clinical challenges associated with post-burn eyelid deformities and evaluates the potential of 3D bioprinting technology as an innovative reconstructive solution. Conventional surgical techniques often face limitations such as donor site morbidity, insufficient tissue compatibility, and poor aesthetic outcomes. 3D bioprinting offers individualized, biocompatible, and functionally integrated tissue substitutes. The article reviews recent experimental and preclinical research, highlighting bio-ink components, cell types, and scaffold designs relevant to periorbital reconstruction.

Keywords. 3D bioprinting, eyelid burns, reconstructive surgery, regenerative medicine, bio-ink, tissue engineering, mesenchymal stem cells

Introduction

Eyelid burns pose a serious clinical and reconstructive challenge due to the delicate anatomy and functional significance of the periocular region. The eyelid plays a critical role in corneal protection, tear film distribution, and facial aesthetics. Thermal injuries to this area often lead to cicatricial ectropion, lagophthalmos, corneal exposure, and secondary infections, potentially resulting in irreversible vision loss or blindness [1]. Conventional reconstructive approaches rely on skin grafts, flaps, or composite tissue transplantation, but often result in suboptimal cosmetic and functional outcomes. In this context, 3D bioprinting has emerged as a promising regenerative solution, allowing for the layer-by-layer fabrication of living tissue constructs tailored to the patient's anatomy and cellular profile.

1. Clinical Consequences of Eyelid Burns

Post-burn eyelid defects commonly present the following complications:

- Anterior and posterior lamellar contractures
- Lagophthalmos with corneal exposure

- Recurrent keratitis and microbial infections
- Unsatisfactory aesthetic appearance and scarring
- Long-term psychosocial distress and facial disfigurement

Repeated surgical interventions are often necessary due to the limited elasticity and availability of periorbital tissue [2]. These challenges call for biologically engineered constructs that can integrate into host tissue and restore both form and function.

2. Fundamentals of 3D Bioprinting Technology

3D bioprinting refers to the additive manufacturing of living tissues using bio-inks composed of cells, growth factors, and supportive biomaterials. The process involves precise digital modeling, usually derived from high-resolution imaging such as CT or MRI, to create custom anatomical scaffolds [3]. Key components include:

- Bio-inks: Collagen, gelatin, hyaluronic acid, fibrin, and poly(lactic-co-glycolic acid) (PLGA)
- Cells: Fibroblasts, keratinocytes, mesenchymal stem cells (MSCs)
- Bioreactors: Controlled environments for cell proliferation and differentiation
- Printing methods: Extrusion-based, inkjet, or laser-assisted bioprinting techniques

3. Reconstructive Potential in Eyelid Surgery

3.1. Patient-specific anatomical modeling

3D scanning technologies allow for the creation of personalized eyelid implants that conform to the patient's precise anatomical structure, reducing graft mismatch and improving cosmetic results [4].

3.2. Enhanced biological integration

Unlike synthetic implants, bioprinted constructs allow for host cell infiltration, vascularization, and tissue remodeling, minimizing the risks of rejection, fibrosis, and infection [5].

3.3. Functional composite tissue engineering

Recent advances in 3D bioprinting have enabled the integration of muscle, vascular, and epithelial layers within a single scaffold, allowing for dynamic eyelid function post-implantation [6].

4. Preclinical Studies and Experimental Evidence

- Murphy and Atala (2014) demonstrated the feasibility of fabricating layered, vascularized tissues using stem cell-laden bio-inks for complex organ reconstruction [7].
- Atala et al. (2020) successfully printed a collagen-based eyelid construct, which showed favorable integration in animal models, with preserved tarsal plate-like rigidity [8].
- Zhao et al. (2022) developed a 3D printed periorbital scaffold embedded with mesenchymal stem cells that supported epithelialization and reduced scarring in rodent models.
- Japanese researchers at RIKEN Institute have announced Phase I clinical trials for 3D printed human ocular tissues (2023), indicating imminent clinical translation.

5. Challenges and Future Perspectives

5.1. Technical limitations

- Maintaining cell viability and differentiation in thick tissue layers
- Achieving sufficient vascularization within printed constructs
- High cost and regulatory hurdles for clinical-grade biofabrication

5.2. Future directions

- Bioactive scaffolds with integrated growth factors and signaling molecules[9].
- Hybrid constructs combining 3D bioprinting with nanotechnology
- Development of universal, off-the-shelf bio-inks for clinical scalability

Conclusion. 3D bioprinting holds transformative potential in the field of reconstructive oculoplastic surgery, particularly for patients with post-burn eyelid deformities. Its ability to create personalized, biologically functional, and integrative tissue constructs may significantly improve both clinical outcomes and quality of life. Further clinical trials and long-term studies are necessary to validate its safety, efficacy, and cost-effectiveness for routine surgical application.

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