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Application Value of 3D Printing Technology in Breast Cancer Treatment

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Abstract: Breast cancer, the most prevalent malignant tumor among women, has shown a rising incidence rate in recent years. Personalized and precise comprehensive treatment is currently considered the optimal approach for breast cancer management. The application of 3D printing technology in the medical field has been expanding, covering areas such as medical devices, anatomical models, tissue engineering scaffolds, tumor models, and drug formulation, drawing significant attention in the field of oncology. This article explores the application value of 3D printing technology in breast cancer treatment, including preoperative planning, radiotherapy, postoperative rehabilitation and adjuvant therapy, and scientific research, aiming to provide new perspectives and methods for clinical breast cancer treatment.

Keywords: 3D printing technology; Breast cancer treatment; Preoperative planning; Radiotherapy; Postoperative rehabilitation

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1. Introduction

Breast cancer has become the most frequently diagnosed malignant tumor among women, with a concerning upward trend in incidence rates in recent years [1]. Traditional breast cancer treatment methods, while capable of controlling the disease to some extent, often lack precision and can cause significant physical harm to patients. With advancements in medical technology, personalized and precise comprehensive treatment plans have emerged as the optimal choice for breast cancer treatment.

At present, 3D printing technology has demonstrated immense potential in the medical field, making its presence felt in various specialized areas. For instance, it enables the creation of customized medical devices tailored to better meet patient needs; it provides highly accurate anatomical models that facilitate medical teaching and research; it contributes to tissue engineering scaffolds that support tissue regeneration and repair; it creates realistic tumor models that offer direct references for cancer diagnosis and treatment; and it aids in drug formulation, ensuring precise dosage control [2-5].

Particularly in the realm of cancer treatment, 3D printing technology has attracted increasing attention due to its unique advantages. It is gradually becoming a powerful "assistant" in supporting cancer therapy.

2. Application of 3D printing technology in preoperative planning for breast cancer treatment

2.1. Printing solid models of breast tumors

In breast cancer surgery, 3D-printed solid models of breast tumors play a pivotal role. Studies have shown that using these models allows for multiple simulations and precise localization of the surgical area. During the actual procedure, surgeons can skillfully avoid major blood vessel branches while ensuring complete tumor removal and preserving as much glandular tissue as possible. This approach significantly reduces surgical time.

Peng *et al.* [6] employed 3D-printed models for preoperative planning in challenging cases, such as patients with recurrent breast cancer after radical surgery accompanied by axillary ulceration and complete brachial plexus damage. The models provided realistic visual representations for both doctors and patients, facilitating preoperative communication. This allowed patients to better understand their condition and subsequent treatment plans. Moreover, the models supported the precise design of surgical strategies, including determining the exact position of transplanted flaps. They assisted surgeons in successfully excising tumors and reconstructing extensive wounds with transplanted flaps, enabling patients at risk of amputation to retain the appearance and normal function of the affected limb.

2.2. Creating surgical navigation templates

Accurate lesion localization is a critical step in breast cancer surgery. Currently, the conventional wire-guided localization method is commonly used. However, this approach has several drawbacks, including the need for an additional preoperative puncture procedure, extended hospital stays, and increased medical costs [7].

The advent of 3D-printed surgical navigation templates offers a novel solution to these challenges. For example, Wu *et al.* [8] utilized 3D printing technology to produce navigation templates, which were employed to assist in breast-conserving surgeries for 88 patients with invasive breast cancer. Postoperative pathological results were promising, with negative surgical margins achieving favorable outcomes.

Reports on the use of 3D-printed navigation templates for breast cancer surgery are becoming increasingly common. This technology enables precise localization of tumors, significantly improving surgical accuracy and safety. It is particularly valuable in the removal of small tumors, demonstrating substantial clinical importance and greatly enhancing the outcomes of breast cancer surgeries.

3. Application of 3D printing technology in radiotherapy for breast cancer treatment

3.1. Customization of individualized radiotherapy bolus

In the radiotherapy phase of breast cancer treatment, 3D printing technology plays a significant role. Specifically, its advantages are evident in the customization of individualized radiotherapy bolus [9-11]. By utilizing patient imaging data, 3D printing technology enables the creation of bolus tailored to the unique contours of each patient's chest wall. These boluses achieve a higher degree of conformity with the chest wall, effectively reducing air gaps

and optimizing dose distribution in the target area, thereby enhancing the precision of radiotherapy.

Research by Yan *et al.* [12] further confirms these advantages, demonstrating that compared to traditional bolus, 3D-printed bolus show superior conformity with the chest wall and outperform in key dosimetric indicators. This suggests that the use of 3D-printed bolus results in more precise and effective radiotherapy, providing better assurance for breast cancer patients undergoing treatment.

3.2. Assisting in radiotherapy planning

In breast-conserving surgery for breast cancer, achieving negative margins while maintaining an aesthetically pleasing appearance is of utmost importance. 3D printing technology plays a crucial role in assisting radiotherapy planning in this context. During breast-conserving surgery, 3D printing enables precise tumor localization, providing accurate data to inform radiotherapy plans [6,13-15].

Based on the detailed tumor information generated by 3D printing, surgeons can perform breast-conserving procedures more scientifically and accurately. This not only facilitates smaller surgical incisions but also ensures the safety of margins, minimizing the risk of residual tumor cells. Additionally, it helps preserve the aesthetic appearance of the breast.

The integration of 3D printing technology into radiotherapy planning undoubtedly enhances the synergy between breast-conserving surgery and radiotherapy, delivering improved treatment experiences and outcomes for breast cancer patients.

4. Application of 3D printing technology in postoperative rehabilitation and adjunctive treatment for breast cancer

4.1. Customization of postoperative implants

In comprehensive breast cancer treatment, surgery plays a critical role. However, the loss of a breast following a mastectomy often negatively affects a patient's physical appearance and quality of life [16]. Breast reconstruction has therefore become an essential component of breast cancer treatment. 3D printing technology plays a significant role in this process, particularly in the customization of postoperative implants.

Huang *et al.* [17] conducted a study utilizing 3D printing technology to create flexible material models, which were implanted into surgical wounds of breast cancer patients as part of breast-conserving surgery. This group was designated as the observation group and compared with a control group of patients who underwent conventional postoperative breast-conserving surgery. The results showed that the observation group had significantly lower rates of postoperative complications. Moreover, their quality-of-life and depression scores were markedly better than those of the control group. The observation group also reported higher satisfaction with postoperative cosmetic outcomes, underscoring the positive impact of 3D-printed custom implants on patient recovery and quality of life.

3.2. Application of drug-delivery devices

Drug-delivery devices offer numerous advantages in tumor treatment, such as precise targeting, enhanced efficacy with reduced toxicity, controlled drug release, overcoming drug resistance, and boosting immune responses. Myung *et al.* [18] developed an innovative 3D-printed localized chemotherapy device capable of achieving high-frequency drug delivery. This device features a sophisticated design that allows it to be

minimally invasively implanted into the patient's body using a trocar needle, with the timing of drug release precisely controlled by its internal microstructure.

Research has demonstrated the device's remarkable therapeutic efficacy, effectively inhibiting tumor growth and metastasis while suppressing the synthesis of drug resistance-related proteins. Alongside its strong anti-tumor effects, it exhibited minimal side effects, highlighting its potential as a novel and superior clinical treatment option for breast cancer patients.

4.3. Application of photothermal therapy scaffolds

Among the diverse approaches to tumor treatment, photothermal therapy has garnered significant attention due to its unique advantages. Specifically, near-infrared light can penetrate the skin without damaging normal tissues, making photothermal therapy a highly safe treatment option with distinct clinical benefits [19,20].

Against this backdrop, Sutrisno *et al.* [21] conducted in-depth research using gelatin and nanomaterials combined with advanced 3D printing technology to develop composite porous scaffolds. Rigorous in vivo and in vitro experiments confirmed that these scaffolds exhibited excellent photothermal properties, demonstrating significant heat ablation capabilities against breast cancer cells.

Notably, due to the mechanical properties of gelatin closely resembling those of soft tissue, these scaffolds not only effectively support tissue repair following breast-conserving surgery but also serve as high-quality carriers for postoperative photothermal therapy. This opens up a novel and highly promising avenue for breast cancer treatment, contributing positively to improved therapeutic outcomes.

5. Application of 3D printing technology in breast cancer research

5.1. Construction of breast cancer and microenvironment tissue models

In the realm of breast cancer research, 3D printing technology plays a critical role, particularly in constructing breast cancer and microenvironment tissue models. This innovation holds significant importance. Traditionally, animal experiments have been the primary research method. However, with advancements in 3D printing technology, the models produced by this approach have paved new directions for research [2].

These models present the potential to reduce or even replace animal experiments while enabling researchers to predict the efficacy and side effects of new therapies or drugs in specific individuals. For instance, Horder *et al.* [22] leveraged the advantages of 3D printing technology to successfully create a breast cancer model. Using this model, they conducted an in-depth study on the interactions between tumor cells and adipocytes. This approach has provided valuable insights into the pathogenesis of breast cancer and facilitated the exploration of more effective treatment strategies, thereby significantly advancing breast cancer research.

5.2. 3D-printed breast tumor biological models

In breast cancer research, 3D-printed biological models of breast tumors have demonstrated unique and irreplaceable value. Some researchers have employed advanced 3D bioprinting techniques to construct in vitro 3D biological tumor models. These models excel at replicating many critical characteristics of in vivo tumors, serving as foundational tools for subsequent research and providing robust support for scientific exploration [23].

By utilizing these models, researchers can gain precise insights into individual responses to various treatment strategies before initiating therapy. This enables the development of safer and more effective

treatment plans, ultimately improving therapeutic outcomes. For example, Hong *et al.* [24] introduced an innovative application of this model to quantitatively evaluate breast cancer cell drug resistance. This method has opened new avenues for addressing the challenge of drug resistance in breast cancer, further advancing research and contributing significantly to the field.

6. Conclusion and outlook

As an emerging manufacturing technology, 3D printing holds vast potential for application in breast cancer treatment. Through its use in preoperative planning, radiotherapy, postoperative rehabilitation, and adjuvant therapy, as well as research, 3D printing technology can provide breast cancer patients with more personalized and precise treatment options, enhancing therapeutic outcomes and improving patients' quality of life.

However, several challenges remain in the application of 3D printing technology in breast cancer treatment. These include the high costs associated with 3D printing, which limit its widespread clinical use, the need for further improvement in the biocompatibility and safety of 3D printing materials, and the necessity to optimize the precision and speed of the technology.

Looking ahead, as 3D printing technology continues to evolve and improve, its application in breast cancer treatment is expected to become increasingly widespread. Furthermore, integrating 3D printing technology with other advanced medical technologies, such as artificial intelligence and big data, may offer even more scientific and effective methods for treating breast cancer.

Disclosure statement

The author declares no conflict of interest.

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