Current Trends in Biomedical Engineering & Biosciences
ISSN: 2572-1151

Juniper Publishers
key to the Researchers

Opinion
Volume 24 Issue 1 - February 2026
DOI: 10.19080/CTBEB.2025.24.556129

Curr Trends Biomedical Eng & Biosci

Engineering the Future of Breast Cancer Therapy: Why Targeting Breast Cancer Stem Cells Requires Biomedical Engineering

Piruz Shadbash[1]*

[1]*Department of Microbiology and Microbial Biotechnology, Faculty of Life Sciences and Biotechnology, Shahid Beheshti University, Tehran, Iran*

Submission: February 12, 2026; **Published:** February 18, 2026

***Corresponding author**: Piruz Shadbash, Department of Microbiology and Microbial Biotechnology, Faculty of Life Sciences and Biotechnology, Shahid Beheshti University, Tehran, Iran

Introduction

Breast cancer remains the most frequently diagnosed cancer and a leading cause of cancerrelated mortality among women worldwide [1]. Despite major advances in early detection and systemic therapies, disease recurrence, metastasis, and therapeutic resistance continue to limit longterm survival. Mounting evidence implicates breast cancer stem cells (BCSCs) as central drivers of these clinical failures [2].

While molecular oncology has identified key signaling pathways sustaining BCSCs, clinical translation of these insights has been disappointing. In this opinion article, I argue that the major bottleneck in effective BCSCtargeted therapy is not a lack of biological knowledge, but a lack of engineeringdriven implementation. Biomedical engineering must be positioned as a core not auxiliary discipline in the future of breast cancer treatment.

Breast Cancer Stem Cells: A Clinical Problem, Not a Theoretical Concept

BCSCs are characterized by selfrenewal capacity, tumor initiation potential, phenotypic plasticity, and resistance to chemotherapy and radiotherapy. These cells are enriched following standard treatments and are strongly associated with metastasis and relapse, particularly in aggressive subtypes such as triplenegative breast cancer (TNBC) [3].

From a clinical perspective, the persistence of BCSCs explains why tumor shrinkage does not necessarily translate into durable remission. Therefore, any therapeutic strategy that fails to address BCSCs is, in effect, incomplete [4].

Why Conventional Approaches Fall Short

Most anticancer therapies are developed and tested in experimental systems that inadequately represent the BCSC niche, including:

- Simplified 2D cultures
- Homogeneous cell populations
- Absence of mechanical and hypoxic cues

These limitations result in therapies optimized for bulk tumor cells rather than the stemlike subpopulation that dictates longterm outcomes. This is where biomedical engineering introduces a paradigm shift.

Engineering the Breast Cancer Stem Cell Niche

Biomedical engineering enables reconstruction of the biophysical and biochemical context in which BCSCs reside [5]. Engineered hydrogels and 3D matrices with tunable stiffness have demonstrated that mechanical cues regulate epithelial–mesenchymal transition (EMT), stemness, and drug resistance in breast cancer [6].

In my opinion, BCSCs cannot be effectively targeted without first engineering their niche. Ignoring the role of matrix stiffness, hypoxia, and spatial organization leads to biologically accurate yet clinically misleading conclusions.

3D Models and TumoronChip Systems: From Hypothesis to Relevance

Engineered 3D breast tumor models, including organoids and bioprinted constructs, preserve BCSC heterogeneity far better than conventional cultures. Microfluidic breast tumoronchip platforms further allow dynamic control over oxygen gradients, nutrient flow, and drug exposure [7]. I strongly believe that future preclinical evaluation of BCSCtargeted therapies should require validation in engineered 3D or microfluidic systems, particularly for aggressive subtypes such as TNBC. These platforms bridge

the translational gap between molecular discovery and patient response.

Nanotechnology and Precision Targeting of BCSCs

BCSCs are rare, adaptive, and phenotypically unstable, making them poor targets for nonspecific cytotoxic agents [4]. Biomedical engineering–driven nanoparticlebased delivery systems offer precision solutions by:

- Targeting BCSC surface markers (e.g., CD44 high /CD24 low)
- Delivering pathwayspecific inhibitors (Wnt, Notch, Hedgehog)
- Reducing systemic toxicity

From a translational standpoint, precision engineering not dose escalation represents the most rational strategy for durable BCSC elimination [8].

A Critical Perspective on Current Limitations

Despite enthusiasm, current engineered BCSC models face important challenges:

- Limited integration of immune components
- Incomplete longterm validation
- Lack of standardization across laboratories

Addressing these issues requires a shift from proofofconcept studies toward robust, scalable, and regulatoryaligned engineering platforms. Novelty alone should no longer be the primary metric of success.

Future Outlook: Integration Is the Key

The future of breast cancer therapy lies in the integration of:

- Biomedical engineering
- Breast cancer biology
- Stem cell science
- Artificial intelligence and datadriven modeling

In my view, the most impactful advances will emerge from closedloop engineered systems capable of diagnosis, therapy, and realtime monitoring of BCSCs within patientspecific tumor models.

Concluding Opinion

Breast cancer stem cells represent a fundamental barrier to curative therapy. Biomedical engineering offers not incremental improvement, but a conceptual reframing of how these cells are studied and targeted. Without engineered platforms that faithfully replicate tumor complexity and enable precision intervention, BCSCfocused therapies will remain scientifically elegant yet clinically insufficient. The future of breast cancer treatment will not be defined solely by better drugs, but by better engineered systems that allow those drugs to succeed.

References

1. Wilkinson L, Gathani T (2022) Understanding breast cancer as a global health concern. The British journal of radiology 95: 20211033
2. Wang L, Jin Z, Kim MC, Kolb R, Zhang W, et al. (2022) Breast cancer stem cells: signaling pathways, cellular interactions, and therapeutic implications. Cancers 14(13): 3287
3. Chen M, Liu S (2025) Breast Cancer Stem Cell Heterogeneity, Plasticity and Treatment Strategies. Cancer Heterogeneity and Plasticity 2.
4. Ali K, Nabeel M , Mohsin F , Iqtedar M, Islam M, et al. (2024) Recent developments in targeting breast cancer stem cells (BCSCs): a descriptive review of therapeutic strategies and emerging therapies. Medical Oncology 41(5): 112
5. Akhtar Z (2024) Exploring biomedical engineering (BME): Advances within accelerated computing and regenerative medicine for a computational and medical science perspective exploration analysis. J. Emerg. Med OA 2: 1-23
6. Shah L, Latif A, Williams KJ, Tirella A (2022) Role of stiffness and physico-chemical properties of tumour microenvironment on breast cancer cell stemness. Acta Biomaterialia 152: 273-289
7. Azimian Zavareh V, Shariati L, Vaseghi G, Savoji H, Javanmard SH, et al. (2022) Three-dimensional in vitro models: a promising tool to scale-up breast cancer research. ACS biomaterials science & engineering 8(11): 4648-4672
8. Tang Y, Chen Y, Zhang Z, Tang B, Zhou Z, et al. (2021) Nanoparticle-based RNAi therapeutics targeting cancer stem cells: Update and prospective. Pharmaceutics 13(12): 2116.

How to cite this article: Piruz S. Engineering the Future of Breast Cancer Therapy: Why Targeting Breast Cancer Stem Cells Requires Biomedical Engineering. Curr Trends Biomedical Eng & Biosci. 2026; 24(1): 556129. DOI: 10.19080/CTBEB.2026.24.5560129

DOI: 10.19080/CTBEB.2026.24.5560129

How to cite this article: Piruz S. Engineering the Future of Breast Cancer Therapy: Why Targeting Breast Cancer Stem Cells Requires Biomedical Engineering. Curr Trends Biomedical Eng & Biosci. 2026; 24(1): 556129. DOI: 10.19080/CTBEB.2026.24.5560129