

REKAYASA JARINGAN DAN SEL PUNCA DALAM REKONSTRUKSI PAYUDARA: TINJAUAN LITERATUR

Beyond Silicone and Flaps in Breast Reconstruction: A Literature Review

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Abstrak

Latar belakang: Rekonstruksi payudara berbasis implan dan flap autologus masih menjadi pilihan rekonstruksi standar, tetapi kedua pendekatan tersebut memiliki keterbatasan, seperti komplikasi terkait implan, morbiditas area donor, kebutuhan operasi revisi, serta hasil yang kurang optimal pada jaringan yang telah mengalami iradiasi. Tujuan: Tinjauan literatur ini merangkum bukti klinis yang relevan mengenai tissue engineering, adipose-derived stem cells (ADSCs), stromal vascular fraction (SVF), cell-assisted lipotransfer, scaffold, hidrogel, dan pencetakan tiga dimensi (3D) dalam rekonstruksi payudara. Metode: Pencarian literatur naratif dilakukan melalui PubMed/MEDLINE, Google Scholar, dan penelusuran daftar referensi hingga Juni 2026. Kata kunci pencarian meliputi breast reconstruction, tissue engineering, ADSC, SVF, cell-assisted lipotransfer, fat grafting, scaffold, hydrogel, dan 3D printing. Artikel dipilih berdasarkan relevansi klinis, kepentingan translasi, serta ketersediaan informasi bibliografis yang dapat diverifikasi. Pembahasan: Autologous fat grafting banyak digunakan untuk perbaikan kontur dan peningkatan kualitas jaringan lunak, tetapi retensi graft masih bervariasi. Strategi berbasis ADSC dan SVF berpotensi meningkatkan keberlangsungan graft melalui angiogenesis, adipogenesis, sinyal parakrin, dan remodeling matriks ekstraseluler, meskipun protokol yang digunakan masih heterogen. Platform scaffold dan hidrogel dapat memberikan dukungan struktural bagi regenerasi jaringan adiposa, sedangkan pencetakan 3D memungkinkan pembuatan konstruksi yang disesuaikan dengan kebutuhan pasien. Bukti klinis saat ini menunjukkan hasil yang menjanjikan, tetapi masih terbatas oleh jumlah studi yang kecil, variasi metode pemrosesan sel, hambatan regulasi, serta perlunya pemantauan onkologis jangka panjang. Kesimpulan: Strategi regeneratif saat ini sebaiknya dipandang sebagai terapi tambahan, bukan pengganti implan dan flap. Rekonstruksi payudara di masa depan kemungkinan akan mengintegrasikan teknik bedah konvensional dengan fat grafting, sel regeneratif, biomaterial, dan desain scaffold yang disesuaikan dengan kebutuhan pasien.

Kata Kunci:

Rekonstruksi Payudara
Rekayasa Jaringan
Sel Punca Turunan Jaringan
Adiposa
Fraksi Vaskular Stromal
Cell-assisted Lipotransfer

Keywords:

Breast Reconstruction
Tissue Engineering
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Abstract

Background: Implant-based and autologous flap breast reconstruction remain standard reconstructive options, but both approaches may be limited by implant-related complications, donor-site morbidity, revision surgery, and suboptimal outcomes in irradiated tissue. Objective: This literature review summarizes clinically relevant evidence on tissue engineering, adipose-derived stem cells (ADSCs), stromal vascular fraction (SVF), cell-assisted lipotransfer, scaffolds, hydrogels, and three-dimensional (3D) printing in breast reconstruction. Methods: A narrative literature search was performed using PubMed/MEDLINE, Google Scholar, and reference-list screening up to June 2026. Search terms included breast reconstruction, tissue engineering, ADSC, SVF, cell-assisted lipotransfer, fat grafting, scaffold, hydrogel, and 3D printing. Articles were selected for clinical relevance, translational importance, and availability of verifiable bibliographic information. Discussion: Autologous fat grafting is widely used for contour refinement and soft-tissue improvement, but graft retention remains variable. ADSC- and SVF-assisted strategies may enhance graft survival through angiogenesis, adipogenesis, paracrine signaling, and extracellular-matrix remodeling, although protocols remain heterogeneous. Scaffold and hydrogel platforms may provide structural support for adipose regeneration, while 3D printing may enable patient-specific constructs. Current clinical evidence is encouraging but remains limited by small studies, heterogeneous cell-processing methods, regulatory barriers, and the need for long-term oncologic surveillance. Conclusion: Regenerative strategies should currently be considered adjuncts rather than replacements for implants and flaps. Future breast reconstruction will likely integrate conventional surgery with fat grafting, regenerative cells, biomaterials, and patient-specific scaffold design.



INTRODUCTION

Breast reconstruction is an important component of post-mastectomy care because it restores breast contour and may support body image, psychosocial recovery, and quality of life after oncologic treatment. Current options are commonly grouped into implant-based reconstruction and autologous tissue reconstruction, and both remain established methods for volume restoration. Implant-based reconstruction is widely used because it is technically familiar and avoids donor-site morbidity, but infection, seroma, capsular contracture, rippling, malposition, and revision surgery remain clinically relevant complications. Autologous reconstruction provides vascularized tissue and may be advantageous in selected complex or irradiated defects, but it requires donor tissue, longer operative planning, and carries donor-site morbidity. These limitations have encouraged interest in regenerative breast reconstruction, a concept that aims to restore soft-tissue biology rather than simply replace volume (Donnelly et al., 2020; Fang et al., 2021). Tissue engineering, ADSCs, SVF, cell-assisted lipotransfer, injectable scaffolds, hydrogels, and 3D printing are increasingly discussed as strategies to improve adipose regeneration, tissue quality, and patient-specific reconstruction. Autologous fat grafting is the clinical bridge between conventional reconstruction and regenerative surgery because it can correct contour deformity, soften implant edges, and improve selected post-lumpectomy or post-radiotherapy soft-tissue defects. Its main limitation is unpredictable volume retention, which has driven research into cell enrichment and scaffold-assisted adipose tissue engineering (Donnelly et al., 2020; De Sario Velasquez et al., 2025; Li et al., 2026).

METHODS

This article was prepared as a narrative literature review, not as a systematic review. Therefore, PRISMA flow reporting, database-specific search counts, formal risk-of-bias scoring, and meta-analysis were not performed. A literature search was conducted using PubMed/MEDLINE, Google Scholar, and reference-list screening up to June 2026. Search terms included breast reconstruction, postmastectomy reconstruction, tissue engineering, adipose-derived stem cells, ADSC, stromal vascular fraction, SVF, cell-assisted lipotransfer, fat grafting, lipofilling, scaffold, hydrogel, biomaterial, 3D printing, and bioprinting. Priority was given to peer-reviewed articles with verifiable bibliographic information, clinical relevance to breast reconstruction, and translational relevance to regenerative soft-tissue surgery. Unverified or incomplete references were excluded from the final reference list to avoid unsupported citation..

RESULTS

Based on current evidence, tissue engineering and stem-cell-assisted strategies should be considered adjuncts rather than replacements for implants and flaps. Their most realistic current roles include contour refinement, revision reconstruction, improvement of selected irradiated soft tissue, correction of partial breast defects, and enhancement of fat-graft persistence in selected patients. The future of breast reconstruction is likely to be hybrid, combining conventional structural reconstruction with regenerative adjuncts. In this

model, implants or flaps may provide reliable volume, fat grafting may refine contour, regenerative cells may support tissue quality, and scaffolds or 3D printing may guide patient-specific shape and tissue organization (Goncalves et al., 2022; Jeon et al., 2021; Shimizu et al., 2026).

Table 1. Summary of regenerative strategies in breast reconstruction

Strategy	Main rationale	Potential value	Main limitation	Key references
Autologous fat grafting	Contour refinement, volume restoration, selected irradiated tissue support	Repeatable and minimally invasive	Variable retention and possible staged procedures	Arshad et al. (2016); Laloze et al. (2018); Goncalves et al. (2022)
ADSC enrichment	Paracrine signaling, angiogenesis, adipogenesis	May improve graft retention	Processing and regulatory heterogeneity	Fang et al. (2021); Shimizu et al. (2026)
SVF-assisted CAL	Mixed regenerative cellular support	Intraoperative clinical practicality	Variable cell yield and preparation method	Tissiani & Alonso (2016); Gentile et al. (2015, 2019); Jeon et al. (2021)
Injectable scaffold/hydrogel	3D matrix for adipose regeneration	Potential structural and biological support	Mechanical strength and degradation control	Pruzzo et al. (2026); Li et al. (2026)
3D-printed scaffold	Patient-specific geometry and porosity	Customized reconstruction planning	Mostly translational; vascularization and approval issues	De Sario Velasquez et al. (2025); Li et al. (2026)

Discussion

Conventional Breast Reconstruction and the Regenerative Shift

Conventional breast reconstruction has historically relied on prosthetic replacement or autologous tissue transfer. Implants can restore breast mound volume but do not regenerate living tissue, whereas flap reconstruction transfers vascularized tissue but adds donor-site considerations (Donnelly et al., 2020). Regenerative reconstruction reframes the surgical objective from filling a defect to supporting tissue restoration. In this framework, fat grafting, ADSC biology, SVF enrichment, scaffold design, hydrogel delivery, and 3D printing may act as complementary tools rather than isolated replacements for established operations (Fang et al., 2021; Pruzzo et al., 2026).

Autologous Fat Grafting as a Foundation for Regeneration

Autologous fat grafting is used in breast reconstruction to correct contour irregularity, improve soft-tissue thickness, and refine implant- or flap-based reconstruction. Fat graft survival depends on harvesting technique, processing method, injection plane, recipient-site vascularity, and early revascularization (Arshad et al., 2016; Laloze et al., 2018). Transferred adipocytes are vulnerable to ischemia before sufficient neovascularization occurs; therefore, fat necrosis, oil cysts, calcification, and partial resorption may occur after grafting. Systematic reviews of cell-assisted lipotransfer show that fat survival may improve with cell enrichment, but the magnitude of benefit is inconsistent across anatomical sites and study designs (Laloze et

al., 2018). Oncologic safety is central when fat grafting is used after breast cancer surgery. A 2022 systematic review and meta-analysis reported that autologous fat grafting did not appear to adversely affect overall survival, disease-free survival, or local recurrence in available clinical evidence, although careful patient selection and follow-up remain necessary (Goncalves et al., 2022)

Adipose-Derived Stem Cells

ADSCs are mesenchymal stromal/stem cells obtained from adipose tissue and are biologically attractive for breast reconstruction because adipose tissue is abundant, accessible, and relevant to breast soft-tissue restoration. ADSCs may support tissue repair through adipogenic potential, angiogenic signaling, immunomodulation, and paracrine secretion rather than direct differentiation alone (Fang et al., 2021). In cell-assisted lipotransfer, lipoaspirate is enriched with ADSCs, SVF, or adipose-derived regenerative cells before reinjection. This strategy is intended to improve graft survival by increasing the regenerative cell population within the graft, but studies vary in culture expansion, intraoperative processing, cell dose, viability, and outcome measurement (Arshad et al., 2016; Laloze et al., 2018). The most recent meta-analytic evidence comparing ADSC-enhanced and conventional fat grafting suggests improved graft retention without a clear signal of increased complications or recurrence, but the authors emphasize the need for standardized protocols and longer follow-up. Therefore, ADSC-enhanced reconstruction remains promising but should be interpreted as an adjunctive and evolving technique (Shimizu et al., 2026).

Stromal Vascular Fraction and Cell-Assisted Lipotransfer

SVF is a heterogeneous cellular fraction derived from adipose tissue and contains stromal cells, endothelial-lineage cells, pericytes, immune cells, and extracellular-matrix components. This mixed cellular composition may support angiogenesis, immunomodulation, and adipose remodeling, but it also creates variability between preparation methods (Tissiani & Alonso, 2016; Gentile et al., 2015). Tissiani and Alonso performed a prospective controlled trial of SVF-enriched fat grafting in secondary breast reconstruction and used MRI-based volumetric assessment, patient satisfaction, aesthetic outcomes, and complication analysis. Gentile and colleagues compared enhanced SVF fat-grafting methods and reported clinical interest in graft maintenance, although their findings should be interpreted in the context of technique-specific processing and nonuniform protocols. Jeon et al. evaluated cell-assisted lipotransfer with SVF for contour deformities of autologous reconstructed breasts and reported that SVF-assisted CAL was effective for improving graft survival in that setting. Nevertheless, systematic reviews conclude that CAL studies often have limited sample sizes, heterogeneous techniques, and incomplete long-term patient-reported or oncologic outcomes (Arshad et al., 2016; Laloze et al., 2018).

Scaffolds, Hydrogels, and 3D Printing

Scaffold-assisted adipose tissue engineering attempts to overcome the structural limitations of injectable fat grafting by providing a three-dimensional environment for cell attachment, vascular ingrowth, and tissue organization. Ideal scaffolds for breast reconstruction should be biocompatible, biodegradable, mechanically

appropriate, supportive of adipogenesis and angiogenesis, and compatible with oncologic surveillance (Donnelly et al., 2020; Pruzzo et al., 2026). Injectable scaffolds, many of which are hydrogel based, are being developed to restore soft-tissue volume while delivering biological cues for host-driven adipogenesis and angiogenesis. Natural hydrogels may support cell viability and differentiation, whereas synthetic hydrogels may provide tunable mechanical properties and degradation rates. 3D printing may allow patient-specific scaffold geometry, controlled porosity, and preoperative customization of breast shape (Li et al., 2026; Pruzzo et al., 2026). However, current 3D-printed and hydrogel-based breast scaffold approaches remain largely translational because large-volume vascularization, infection control, mechanical matching, degradation behavior, manufacturing standardization, and regulatory approval remain unresolved (De Sario Velasquez et al., 2025; Li et al., 2026).

Oncologic Safety and Clinical Translation

Regenerative breast reconstruction must be evaluated within an oncologic context because many patients undergoing reconstruction are breast cancer survivors. Autologous fat and adipose-derived cells contain stromal and paracrine components that could theoretically influence the tumor microenvironment, angiogenesis, or imaging interpretation (Fang et al., 2021; Goncalves et al., 2022). Available clinical evidence for conventional autologous fat grafting is generally reassuring regarding recurrence outcomes, but this evidence cannot be automatically generalized to all stem-cell-enriched or scaffold-assisted techniques. For ADSC- or SVF-assisted reconstruction, longer follow-up and subgroup reporting by tumor biology, stage, radiotherapy, disease-free interval, and surveillance findings remain important (Goncalves et al., 2022; Shimizu et al., 2026). Clinical translation is also limited by cost, regulatory classification, device dependency, cell-processing variability, and inconsistent outcome reporting (Arshad et al., 2016; Laloze et al., 2018; Shimizu et al., 2026). Future studies should report cell yield, viability, processing method, injection technique, volumetric assessment, complications, BREAST-Q or equivalent patient-reported outcomes, and oncologic endpoints (Jeon et al., 2021; Laloze et al., 2018; Shimizu et al., 2026).

CONCLUSION

Breast reconstruction is moving from a purely structural model toward a regenerative and hybrid model. Silicone implants and autologous flaps remain essential, but ADSCs, SVF, CAL, injectable scaffolds, hydrogels, and 3D printing are expanding the biological possibilities of reconstruction. Current evidence supports cautious optimism, particularly for fat grafting and selected cell-assisted approaches, but routine replacement of established reconstructive methods is not yet justified. Standardized protocols, objective volume measurement, validated patient-reported outcomes, cost analysis, and long-term oncologic follow-up are required before broader clinical adoption.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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