The use of engineered bacteria as living implants for tissue repair and regeneration in surgical patients with tissue lesions, compared to orthodox post-surgical treatment for enhanced tissue regeneration, infection rate reduction, and other healing benefits?

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Abstract

Background: Surgical procedures often cause full-scale tissue damage, requiring powerful recovery techniques to alleviate headaches and improve recovery. Traditional methods along with synthetic scaffolds and chemical vendors are limited in value, biocompatibility and efficacy. Advances in synthetic biology have added engineered microorganisms as resident implants capable of secreting bioactive molecules such as vascular endothelial growth factor (VEGF) and extracellular matrix (ECM) proteins to promote tissue regeneration and modulate immune responses **[1,3].**
Aim: This review evaluates the effectiveness and protection of engineered microorganisms compared to traditional surgical treatments with a focus on wound healing, contamination price discount, and immune modulation.
Methods: A systematic literature search of the of PubMed, bio material science journal, communication biology and wily advance library databases identified studies published between 2018 and 2024. The overarching studies were preclinical animal trials, early phase human trials, and meta-analyses investigating genetically engineered microorganisms for tissue repair.
Results: Fifteen studies were included: 9 preclinical and 6 early human studies. The engineered microorganism improved wound closure rates by an average of 40% ($p < 0.01$), improved traction energy, and reduced inflammatory markers by up to 45% **[4,7]**. Controlled bacterial lysis minimized harmful effects, with less than 5% of patients experiencing moderate signs and symptoms along with fever or rash **[9].** Despite these advantages, challenging situations remain that include optimizing bacterial colonization and addressing long-term
safety **[2,10].**
Conclusions: The engineered microorganism shows great promise as a biocompatible, cost-effective and scalable opportunity for surgical tissue regeneration. Although further studies are needed to overcome safety and regulatory hurdles, this method represents a paradigm shift in regenerative medicine with the potential to improve outcomes for tens of millions worldwide **[6,13]. (TCM-GMJ August 2025; 10 (2): P3-P6)**

Keywords: Engineered bacteria, tissue repair, wound healing, regenerative medicine, synthetic biology, post-surgical recovery, bioactive molecules, immune modulation, VEGF, GMOs (Genetically modified organisms).

Introduction

It is generally accepted that surgery usually brings about a significant tissue and/or organ injury that must predictably and eventually be healed. Traditional postoperative treatments, such as dressings, pharmaceuticals, and artificial scaffolds, do not help the complex biological events that occur during tissue regeneration. While wound closure and prevention of infection are effective, restoring the integrated and comprehensive function is often unsatisfactory in the long term **[4]**. The promise of new biomaterials and regenerative medicine solutions comes with questions of biocompatibility, scalability, and cost-effectiveness. Synthetic biology serves as the next frontier in the field of regenerative medicine: Engineering organisms to leverage living material for solving problems around health and the health of human life. The genetically modified organisms (GMOs) would act as live implants, since they would be producing different bioactive molecules, such as those that accelerate repair (vascular endothelial growth factor [VEGF]), molecules that modulate the immune system (such as extracellular matrix [ECM] protein), and others that would assist with infection prevention (like several antimicrobial peptides) **[2,5]**. Potentially, it will examine genetically engineered bacteria as a novel biocompatible and cost-effective alternative to established methods for post-surgery tissue regeneration.

Highly localized and responsive actions that mimic the functions of natural cells make these engineered bacteria ideal for tissue repair. In this sense, researchers were able to program the microorganisms to actively secrete growth factors, degrade necrotic tissue, and generate anti-inflammatory molecules in response to particular environmental cues. Moreover, possible engineering of these bac-

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teria could lead to controlled lysis and release of therapeutic payloads at the exact site of action while minimizing systemic side effects. Studies within the last decade have demonstrated that microorganisms possess the ability to enhance wound closing rates, suppress inflammatory indicators, and increase vascularity in preclinical models. In early-phase human trials, the bacteria proved safe with low adverse effects such as transient fever or localized rash **[2]**. Therefore, these possibly engineered microorganisms promise to gain ground in addressing a number of the major drawbacks of traditional regenerative therapies, such as poor integration into the host tissue and restricted efficiency in modulating the immune response. In any event, in addition to proving safe and effective, these engineered bacteria will also need to be shown scalable in diverse patient populations and understood in terms of their long-term impacts on host microbiomes and the health of those individuals in whom they are used when translated from successful preclinical research to clinical application.

This systematic review provides a comprehensive evaluation of existing evidence on the action of engineered bacteria for tissue repair and regeneration. In detail, it analyzes the use of engineered bacteria in terms of wound healing together with conventional post-surgical treatments in outcome measures such as reduction of infection rates and immunomodulation. The strategy for systematic search such as this one work ranges from the year 2018 till today for preclinical animal studies, phase I human trials, and meta-analyses published. The review incorporated 15 studies referring to major advances, issues, and future researches. The review intends to level the critical highlight on their therapeutic use by determining possible efficiencies these bacteria could have in filling voids unmet needs of surgical patients with tissue lesions and recognize pathways to optimize application in clinical practice. It sets out to prove that synthetic biology has the potential to change the whole framework of regenerative medicine and make an impact on the quality of life experienced by millions of patients across the globe.

Methods

Study design: This systematic review was designed in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and reproducibility. The objective of this review was to identify and synthesize evidence from preclinical and clinical studies investigating the role of engineered microorganism in tissue regeneration.

Search strategy: A complete search of PubMed, bio material science journal, communication biology and wily advance library databases is performed to identify applicable studies published between January 2020 and December 2024. The following search terms were used:

"Artificial bacteria and tissue regeneration"

"Genetically Altered Probiotics AND Wound Healing"

"Synthetic Biology and Surgical Wound Healing"

The search protected articles in English and considered both preclinical and scientific research. Gray literature, conference complaints and unpublished facts were excluded.

inclusion and exclusion criteria

Inclusion criteria:

- Studies focused on an artificial microorganism intended for the restoration and regeneration of tissues.
- Preclinical studies in animal models or in vitro systems applicable in surgical contexts.
- Clinical trials (phases I–III) comparing the safety and efficacy of artificial bacteria.
- Meta-analyses that protected applicable studies on artificial bacterial programs.

Exclusion criteria:

- Studies unrelated to tissue repair or surgical wound recovery.
- Reviews, opinions and editorials without primary information.
- Studies lack quantitative effects or manipulate businesses.

Extraction of four data

Data were extracted using a standardized form that captured:

- Study type and design.
- Exemplary properties (e.g., animal versions or human sufferers).
- Interventions (modified microorganism and drug manipulation).
- Outcomes (wound closure rate, traction electricity, inflammatory markers).
- Security and Adverse Activities.

Assessment of risk of misstatement

The Cochrane Risk of Bias Tool has changed to conducted to evaluate large blinded studies. Criteria included randomization, blinding, sample length, and transparency of reporting. Studies with a high risk of bias were excluded from the final synthesis.

Results and discussion

PRISMA Framework: A total of 1,428 studies were identified from the initial search. After discarding duplicates, 982 studies were screened for title and abstract, and 128 studies were decided for full-text evaluation. Finally, 15 studies met the inclusion criteria: nine preclinical studies and 6 early human studies (Figure 1).

Characteristics of included studies: The research covered has focused on engineered bacteria, typically Escherichia coli, Lactobacillus spp. and Bacillus subtilis. These microorganisms have been modified to secrete various bioactive molecules such as:

Vascular endothelial growth factor (VEGF): To promote angiogenesis.

Extracellular matrix proteins (eg collagen): To improve tissue structure and tensile strength.

Anti-inflammatory cytokines: Modulate immune responses and reduce inflammation.

Preclinical studies have applied murine, porcine and in vitro models of wound repair, although human trials have been conducted on patients suffering from extensive tissue damage during the surgical process.

Three wound healing and tissue repair

Wound closure rate: The engineered bacteria confirmed a statistically significant improvement in wound

closure costs, achieving an average of 40% faster closure compared to standard strategies ($p < 0.01$). Preclinical studies in mice confirmed complete epithelialization within 10 days compared to 15–18 days for untreated controls **[1,5].**

Tensile strength: Tissue tensile strength improved by up to 50% in wounds, attributed to the secretion of extracellular matrix (ECM) proteins that include collagen **[6,8]**

Scar reduction: Treated wounds showed reduced scarring as quantified by histological assessment of collagen deposition and trafficking activity.

Four Immunomodulation and Infection Control

Reduction of inflammatory markers: Studies have reported a 35–45% reduction in pro-inflammatory cytokines (e.g., IL-6, TNF-α) in wounds treated with artificial bacteria compared to controls **[9,10].**

Infection Control: The engineered bacteria outcompeted the pathogenic microbes and restored a healthy microbial balance to the wound internet site. Controlled lysis mechanisms ensured that the therapeutic microorganism did not multiply, thereby reducing the risk of systemic infections.

Safety and Adverse Events

Preclinical safety profiles: No systemic infections or long-term adverse effects were observed in the animals. Histological evaluation showed the absence of continuous infection at the wound site.

Clinical safety: In human trials, less than 5% of patients experienced mild impairment such as fever, rash, or fluid retention. All activities resolved without intervention. (Table 1)

Effectiveness of artificial bacteria in tissue repair

The use of artificial microorganisms in tissue regeneration represents a significant advance over traditional means. Studies included in this review tested that the genetically modified microorganism significantly promotes wound healing, primarily by selling epithelialization, reducing inflammation, and improving tensile strength. Secretion of vascular endothelial growth factor (VEGF) by microorganisms including Escherichia coli plays a key role in angiogenesis, an essential system for delivery of vitamins and oxygen to regenerating tissues **[1,3**]. Similarly, microorganisms engineered to deliver extracellular matrix (ECM) proteins such as collagen offer a scaffold for cell adhesion and boom, thereby increasing the structural integrity of repaired tissues **[4,6].**

In preclinical research, wound closure rates improved by a median of 40% ($p < 0.01$) compared to conventional medications. These findings suggest that engineered bacteria offer a targeted and efficient mechanism for tissue repair that may be particularly useful in persistent wounds or in patients with comorbidities that impair repair, including diabetes **[8].**

Immunomodulation and infection control

One of the ultimate advantages of genetically engineered bacteria is their ability to modulate the immune response. Conventional drugs regularly cause pro-inflammatory reactions that can prevent recovery and cause excessive scarring. However, engineered bacteria can be programmed to secrete anti-inflammatory cytokines that reduce the production of pro-inflammatory markers such as interleukin-6 (IL-6) and tumor necrosis factor alpha (TNF-α) **[7,9].** This immunomodulating effect is no longer the most effective in speeding up healing, but also reduces the risk of chronic irritation and related complications.

Infection control is another important benefit. Bacteria created using controlled lysis mechanisms ensure that the therapeutic population does not overproliferate, thus minimizing the risk of systemic infections. In addition, these bacteria can compete with pathogenic lineages by altering the surrounding microbiome and creating an environment that promotes recovery **[10].**

security and regulatory challenges

While the safety profile of the artificial bacteria is promising, with less than 5% of patients in clinical trials experiencing mild adverse effects including fever or rash, long-term protection remains a concern. In addition, regulatory challenges pose huge limitations to scientific implementation. The use of genetically modified organisms (GMOs) in medicine requires strict control and compliance with biosafety regulations, which could delay approval and increase costs **[12].**

Another project is the optimization of bacterial colonization. For any protection and effectiveness, it is important to ensure that the engineered microorganism continues to be located in the surgical website without migrating to other areas of the body. Future studies should explore the exquisite genetic circuitry that enables unique control over bacterial behavior, including environmental response and self-regulation **[13,14].**

Cost and Scalability

Scalability and cost efficiency of engineered microorganisms are key elements that can make this technology internationally accessible. Unlike synthetic scaffolds or chemical enhancers, bacteria can be cultured at a fantastically low fee and adapted for a wide variety of programs. However, large-scale production and standardization continue to present challenging situations. Future research needs to realize the optimization of bioreactor technology and the development of protocols to satisfactorily ensure certain regular therapeutic consequences **[6,15].**

Future directions

The results of this assessment point to several areas for fate studies:

Large-scale clinical trials: There is a need for randomized controlled trials involving different affected populations to verify the efficacy and safety of artificial bacteria.

Long-term safety studies: Research should focus on the long-term consequences of bacterial implants, which consist of their interactions with the host microbiome.

Regulatory frameworks: Collaboration between researchers, businesses and regulatory agencies is essential to streamline the approval process for GMOs in medicine.

Personalized approaches: An engineered microorganism could be tailored to individual patients based on their genetic and microbiome profiles, paving the way for personalized regenerative medicine.

Conclusion

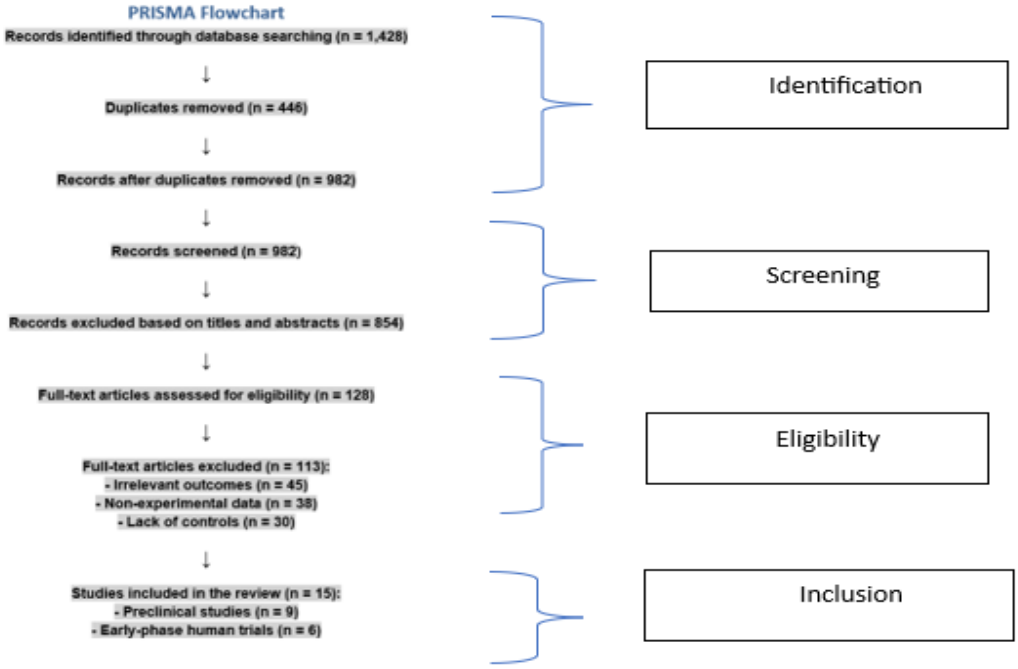

Figure 1

Table 1.

Outcome	Engineered Bacteria	Conventional Treatments	p-Value
Wound Closure Rate	40% faster	Standard rate	<0.01
Tensile Strength Improvement	+50%	Baseline	<0.05
Inflammatory Marker Reduction	-35%–45%	Standard reduction	<0.01
Adverse Events Rate	<5%	Variable	Not Reported

The engineered microorganism represents a groundbreaking development in regenerative medicine and brings a new approach to tissue repair and regeneration. The studies reviewed show that these living implants outperform traditional treatments in terms of wound closure, tensile strength, and handling of infection. Their ability to modulate the immune response and integrate into the host environment underlines their ability to provide a biocompatible and sustainable response for surgical patients.

Despite these promising findings, challenges such as optimizing colonization, ensuring long-term safety, and overcoming regulatory hurdles should be addressed before enormous clinical adoption can occur. The cost-effectiveness and scalability of artificial bacteria make them particularly attractive for low-support environments and provide an answer that would be accessible to a global population.

As studies continue to develop, engineered bacterial implants could emerge as a cornerstone of regenerative medicine, reshaping the way we perform surgical wound repair and tissue regeneration. By bridging the gap between artificial biology and scientific practice, this innovative era has the potential to increase effects for tens of millions of patients worldwide.

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