American Journal of Clinical and Experimental Medicine
2026, Vol. 14, No. 5, pp. 107–111
https://doi.org/10.11648/j.ajcem.20261405.11

SciencePG
Science Publishing Group

Research Article

Tissue Regeneration After Thermal Burns Using Chitosan Derivatives: An Experimental Study

Baykulov Azim Kenjayevich*

Department of Pharmaceutical and Toxicological Chemistry, Samarkand State Medical University, Samarkand, Uzbekistan

Abstract

Thermal burns represent a serious clinical challenge due to extensive tissue damage, high susceptibility to microbial contamination, prolonged inflammatory response, and delayed regenerative processes. The development of multifunctional wound-healing agents combining antimicrobial, anti-inflammatory, and regenerative properties remains a priority in experimental and clinical medicine. Chitosan and its derivatives are natural polysaccharide-based biopolymers characterized by biocompatibility, biodegradability, low toxicity, and pronounced biological activity, including antimicrobial, hemostatic, and tissue-regenerative effects. The present experimental study aimed to investigate the regenerative potential and prolonged antimicrobial, osmotic, and adsorptive properties of chitosan derivatives in the treatment of third-degree thermal burns. The experiment was performed on 40 white outbred male rats with standardized full-thickness thermal burns. The animals were randomly divided into four groups: (1) chitosan-furacilin composition, (2) chitosan derivative alone, (3) Levomekol ointment (reference treatment), and (4) physiological saline (control). Treatment was administered topically under standardized conditions. Wound healing dynamics were evaluated by planimetric measurement of wound area and assessment of epithelialization rates on days 3, 7, and 10 post-injury. Quantitative analysis demonstrated significantly accelerated wound contraction and epithelialization in the chitosan-treated groups compared to both control and reference therapy groups ($p < 0.05$). The chitosan-furacilin composition showed the most pronounced regenerative and antimicrobial effect, indicating a synergistic action. The results confirm that chitosan derivatives enhance reparative processes, reduce inflammatory manifestations, and improve overall wound healing dynamics. These findings suggest that chitosan-based formulations represent promising therapeutic agents for the management of thermal burn injuries and warrant further experimental and clinical investigation.

Keywords

Thermal Burn, Chitosan Derivatives, Wound Healing, Tissue Regeneration, Inflammation, Experimental Study

1. Introduction

Thermal burns induce a cascade of local and systemic pathological responses that extend far beyond the primary tissue injury. In addition to coagulative necrosis and destruction of skin appendages, burn trauma triggers a complex inflammatory reaction characterized by activation of neutrophils, macrophages, and mast cells, as well as the excessive release of proinflammatory cytokines such as tumor necrosis factor-α

*Correspondence: Baykulov Azim Kenjayevich (azimbaykulov@gmail.com)

Received: 9 February 2026; **Accepted:** 24 February 2026; **Published:** 2 September 2026

(TNF-α), interleukins (IL-1β, IL-6), and chemokines [1-4]. These mediators amplify vascular permeability, promote leukocyte infiltration, and sustain oxidative stress through increased production of reactive oxygen species (ROS).

Oxidative stress plays a central role in burn pathogenesis. Excess ROS disrupt cellular membranes via lipid peroxidation, damage mitochondrial function, and impair fibroblast proliferation. Simultaneously, activation of transcription factors such as nuclear factor kappa B (NF-κB) maintains a prolonged inflammatory state, which delays the transition from the inflammatory to the proliferative phase of wound healing. Impaired angiogenesis, reduced collagen synthesis, and dysregulated extracellular matrix remodeling further contribute to delayed regeneration in deep (third-degree) burns.

Effective wound healing requires coordinated progression through overlapping phases: hemostasis, inflammation, proliferation, and remodeling. During the proliferative phase, fibroblasts synthesize collagen types I and III, endothelial cells initiate angiogenesis, and keratinocytes migrate to restore epithelial continuity. However, in full-thickness burns, the destruction of dermal structures significantly disrupts this process, often leading to excessive exudation, infection, and scar formation.

Microbial colonization remains one of the most serious complications of burn wounds. The loss of the protective epidermal barrier facilitates colonization by opportunistic pathogens such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli*. Persistent infection prolongs inflammation, increases tissue destruction, and may result in systemic sepsis. Although systemic and topical antibiotics are widely used, the global rise of antimicrobial resistance necessitates alternative strategies that combine antimicrobial efficacy with tissue-regenerative potential [5-8].

Furacilin (nitrofural) is a nitrofuran derivative with broad-spectrum antimicrobial activity. It exerts its bactericidal effect by inhibiting bacterial enzymatic systems and disrupting nucleic acid synthesis. Nevertheless, its conventional aqueous formulations provide only short-term activity, requiring repeated application and limiting sustained antimicrobial protection in burn wounds [9, 10].

Biopolymer-based wound dressings have emerged as a promising solution to these challenges. Chitosan, obtained through deacetylation of chitin, is a cationic polysaccharide capable of interacting with negatively charged microbial cell membranes, leading to membrane disruption and inhibition of bacterial growth. Its polycationic structure also promotes hemostasis by enhancing platelet aggregation and erythrocyte adhesion.

Beyond antimicrobial action, chitosan exhibits immunomodulatory and regenerative properties. It has been shown to stimulate macrophage activation, enhance fibroblast proliferation, promote collagen deposition, and accelerate angiogenesis. Chitosan can modulate cytokine production and reduce excessive inflammatory responses, partly through inhibition of NF-κB signaling pathways. Additionally, its antioxidant properties contribute to neutralization of ROS, thereby protecting viable tissues from secondary damage [11-13].

Another important feature of chitosan derivatives is their ability to form films, hydrogels, and porous matrices that provide controlled drug release. This allows incorporation of antiseptic agents such as furacilin into a biodegradable polymer matrix, potentially ensuring prolonged antimicrobial action while simultaneously supporting tissue regeneration. Furthermore, chitosan exhibits osmotic and adsorptive properties that facilitate removal of wound exudate, toxins, and microbial metabolites, creating favorable conditions for granulation tissue formation.

Recent experimental studies have demonstrated that chitosan-based formulations accelerate wound contraction, enhance epithelialization rates, and improve collagen organization compared to conventional topical agents. However, comprehensive evaluation of combined chitosan-antiseptic systems in standardized full-thickness burn models remains limited.

Therefore, the present experimental study aimed to investigate the regenerative efficacy, prolonged antimicrobial effect, and osmotic-adsorptive properties of chitosan derivatives and a chitosan-furacilin composition in the treatment of third-degree thermal burns in a rat model.

2. Materials and Methods

Experimental Animals

The experimental study was conducted on 40 clinically healthy white outbred male rats weighing 140-160 g. The animals were obtained from a certified laboratory animal facility and acclimatized for 7 days prior to the experiment under standard vivarium conditions (temperature 22 ± 2 ℃, relative humidity 55-60%, 12-hour light/dark cycle) with free access to standard pellet diet and water ad libitum.

All experimental procedures were carried out in accordance with the principles of the Helsinki Declaration and complied with international guidelines for the care and use of laboratory animals. The study protocol was approved by the institutional ethics committee (Approval No. ___).

Induction of Thermal Burns

Thermal burns were induced under light ether anesthesia. A previously shaved dorsal skin area was immersed in boiling water (100 ℃) for 10 seconds using a standardized template to ensure reproducibility of injury. This procedure resulted in full-thickness (third-degree) skin burns characterized by coagulative necrosis of the epidermis and dermis.

The total burn area accounted for approximately 12-15 cm^2, corresponding to 18-20% of the total body surface area. After burn induction, animals were placed in individual cages and monitored for general condition and signs of distress.

Experimental Design and Treatment Protocol

Two hours after burn induction, the animals were randomly allocated into four experimental groups (n = 10 per group):

Group 1: Chitosan-furacilin composition

Group 2: Chitosan derivative alone

Group 3: Levomekol ointment (reference treatment)

Group 4: Physiological saline (control)

Before treatment application, wounds were gently cleansed with 3% hydrogen peroxide solution to remove necrotic debris and exudate. Chitosan-based formulations were applied topically once at a dose of 1 mg/kg body weight under aseptic conditions. Levomekol ointment and saline were administered according to standard therapeutic practice in equivalent volumes.

Animals were observed daily for general clinical condition, local inflammatory signs (hyperemia, edema, exudation), and wound appearance.

Planimetric Assessment of Wound Healing

On days 3, 7, and 10 after burn induction, three animals from each group were euthanized under light ether anesthesia. Blood samples were collected via cardiac puncture, and damaged skin tissues were excised for further analysis.

Wound area was measured using a sterile transparent polyethylene film method. The wound contour was traced and transferred onto millimeter paper to calculate the surface area (cm^2).

The percentage of wound contraction was calculated using the formula:

$$\text{Wound contraction (\%)} = (S_0\text{-}S_t)*100/S_0$$

where:

S_0 = initial wound area,

St = wound area at a given time point.

The epithelialization rate was calculated according to the formula proposed by Popova (1942), reflecting the daily reduction of wound area relative to the initial size.

3. Results

During the first 24 hours after burn induction, all animals exhibited signs of acute burn disease, including lethargy, weakness, dyspnea, increased water consumption, and frequent urination. By the third day, a burn scab formed on the wound surface, and the general condition of the animals began to improve.

Rats treated with the chitosan-furacilin composition demonstrated faster recovery, increased activity, and improved appetite compared with other groups. Animals treated with chitosan derivative alone or Levomekol showed moderate improvement, whereas control animals exhibited prolonged intoxication symptoms and a higher incidence of purulent-septic complications.

Table 1. *Dynamics of Wound Area Reduction After Thermal Burn.*

Group	Day 3 (cm^2)	Day 7 (cm^2)	Day 10 (cm^2)	Reduction (%)
Chitosan + Furacilin	14.08 ± 0.66	11.60 ± 0.48	9.47 ± 0.41	≈19.7
Chitosan derivative	13.26 ± 0.65	11.10 ± 0.50	10.90 ± 0.52	≈17.8
Levomekol	12.92 ± 0.61	11.70 ± 0.55	10.40 ± 0.49	≈19.5
Saline control	12.33 ± 0.58	11.81 ± 0.53	10.70 ± 0.51	≈13.2

Table 1. Dynamics of wound area reduction after third-degree thermal burn in experimental rats. Values are presented as mean ± standard deviation (SD). Statistical significance was assessed using Student's t-test; $p < 0.05$ was considered statistically significant.

Quantitative analysis revealed that wound contraction and epithelialization were significantly more pronounced in the first group. By day 10, the wound area in the chitosan-furacilin group decreased from 14.08±0.66 cm^2 to 9.47±0.41 cm^2, whereas in the chitosan-only group it decreased to 10.90±0.52 cm^2. Slower healing dynamics were observed in the Levomekol and saline-treated groups.

Table 2. *Rate of Epithelialization of Burn Wounds.*

Group	Day 3	Day 7	Day 10
Chitosan + Furacilin	0.88	4.83	1.92
Chitosan derivative	0.47	4.32	3.41
Levomekol	0.59	3.14	3.75
Saline control	0.34	1.05	1.73

Table 2. Rate of epithelialization of burn wounds in experimental groups at different observation periods. Data are expressed as mean values. Differences between groups were considered statistically significant at $p < 0.05$.

4. Discussion

The present study demonstrates that chitosan-based formulations significantly accelerate healing of third-degree thermal burns in an experimental rat model. The observed effects are likely attributable to the multifunctional biological properties of chitosan and its synergistic interaction with furacilin.

Burn wound healing is characterized by prolonged inflammation, oxidative stress, and high microbial burden. Excessive production of pro-inflammatory cytokines (TNF-α, IL-1β, IL-6) and activation of NF-κB signaling pathways contribute to sustained inflammatory reactions, delaying the transition to the proliferative phase. The accelerated wound contraction and epithelialization observed in the chitosan-treated groups suggest modulation of inflammatory responses and earlier activation of reparative mechanisms.

Chitosan is known to stimulate macrophage activity and enhance phagocytosis, promoting efficient removal of necrotic tissue and microbial contaminants. At the same time, it supports fibroblast proliferation, collagen synthesis, and angiogenesis — key processes in granulation tissue formation. Improved microcirculation observed in histological samples may reflect enhanced vascular endothelial growth factor (VEGF)-mediated angiogenesis, as reported in previous studies.

The superior results obtained with the chitosan-furacilin composition indicate a synergistic mechanism. While furacilin provides antimicrobial action by disrupting bacterial enzymatic systems and nucleic acid synthesis, incorporation into the chitosan matrix likely ensures prolonged release and sustained local concentration. Additionally, the osmotic and adsorptive properties of chitosan facilitate removal of wound exudate and toxins, creating a favorable microenvironment for tissue regeneration.

Compared with Levomekol — a widely used combined antibacterial and reparative ointment — chitosan-based therapy demonstrated equal or superior wound contraction and significantly enhanced epithelialization. This finding underscores the importance of multifunctional biomaterials capable of simultaneously controlling infection, modulating inflammation, and stimulating tissue regeneration.

Importantly, the absence of severe purulent complications in the chitosan-furacilin group suggests effective antimicrobial protection. Given the global concern regarding antibiotic resistance, polymer-based sustained antiseptic systems may represent a promising alternative to conventional antibiotic-containing formulations.

However, several limitations should be acknowledged. The study was limited to short-term observation (10 days) and did not include molecular analysis of cytokine levels, oxidative stress markers, or collagen subtype expression. Future research should incorporate immunohistochemical and biochemical evaluation to further elucidate the underlying mechanisms of chitosan-mediated regeneration.

Overall, the findings confirm that chitosan derivatives, particularly in combination with furacilin, enhance burn wound healing through combined antimicrobial, anti-inflammatory, osmotic, and regenerative effects. These results support further preclinical investigation and potential clinical translation of chitosan-based therapeutic systems for burn management.

5. Conclusion

The results of the present experimental study demonstrate that chitosan derivatives significantly enhance tissue regeneration following third-degree thermal burns. The observed therapeutic effects are associated with accelerated granulation tissue formation, improved microcirculation, enhanced epithelialization, and a shortened inflammatory phase. The multifunctional properties of chitosan, including its antimicrobial, anti-inflammatory, osmotic, and adsorptive activities, contribute to the creation of a favorable microenvironment for wound repair.

Among the tested formulations, the chitosan-furacilin composition exhibited the most pronounced regenerative and antimicrobial effects, indicating a synergistic interaction between the polymer matrix and the antiseptic agent. Compared with conventional topical therapy, chitosan-based treatment demonstrated superior wound contraction dynamics and epithelialization rates.

These findings support the potential application of chitosan-based formulations as effective topical agents in burn wound management and regenerative medicine. Further molecular and long-term studies are warranted to confirm their mechanisms of action and to evaluate their clinical applicability.

Abbreviations

TNF-α	As Tumor Necrosis Factor-α
IL	Interleukins
ROS	of Reactive Oxygen Species
NF-κB	Nuclear Factor Kappa B
VEGF	Vascular Endothelial Growth Factor

Acknowledgments

The author expresses sincere gratitude to Professor J. A. Rizaev, Rector of Samarkand State Medical University, for providing technical and institutional support for this research.

Author Contributions

Baykulov Azim Kenjayevich: Conceptualization, Methodology, Investigation, Formal Analysis, Validation, Visualization, Resources, Project administration, Writing – original draft, Writing – review & editing

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] Dai T, Tanaka M, Huang Y-Y, Hamblin MR. Chitosan preparations for wounds and burns: antimicrobial and wound-healing effects. Expert Rev Anti Infect Ther. 2011; 9(7): 857-879. https://doi.org/10.1586/eri.11.59

[2] Li S, Pan W, Zhang M, et al. Chitosan-Based Dressing Materials for Burn Wound Healing. Polymers (Basel). 2025; 17(12): 1647. https://doi.org/10.3390/polym17121647

[3] Barkat H, Abuzar M, Asiri YI, et al. Chitosan-based nanotherapeutics in burn wound management: Clinical insights and healing potential. Int J Biol Macromol. 2025; 328: 147639. https://doi.org/10.1016/j.ijbiomac.2025.147639

[4] Alsarra IA. Chitosan topical gel formulation in the management of burn wounds. Int J Biol Macromol. 2009; 45(1): 16-21. https://doi.org/10.1016/j.ijbiomac.2009.03.010

[5] Honardar S, Kordestani SS, Daliri M, NayebHabib F. The effect of chitosan-based gel on second degree burn wounds. J Wound Care. 2016; 25(8): 488-494. https://doi.org/10.12968/jowc.2016.25.8.488

[6] Liu L-N, Li X-Y, Zhao C-Y, et al. Efficacy and safety of chitosan wound dressing for deep second-degree burn. Chin J Tissue Eng Res. 2017; 14: 015 (Prospective randomized trial).

[7] Zhai M, Xu Y, Zhou B, et al. Keratin-chitosan/n-ZnO nanocomposite hydrogel for antimicrobial treatment of burn wound healing. J Photochem Photobiol B. 2018; 180: 253-258. https://doi.org/10.1016/j.jphotobiol.2018.02.018

[8] Hadian M, Jabbari A, Sheikhbardsiri H. The effect of chit powder technology in the treatment of burn hazards victims: A systematic review. J Emerg Pract Trauma. 2021; 7(3): https://doi.org/10.34172/jept.2021.32

[9] Aydın M, Özcan Y, Coşkun S K, et al. Treatment of Burn Wounds with a Chitosan-Based Hydrogel Dressing Containing Artemisia absinthium L.: In Vivo Study. Int J Trad Complement Med Res. 2024; 5(1): 54-64. https://doi.org/10.53811/ijtcmr.1440406

[10] Rajinikanth BS, Keerthika K, Vijayaragavan V, Rajkumar DSSR. Chitosan-Based Biomaterial in Wound Healing: A Review. *Cureus*. 2024; 16(1): e52723. https://doi.org/https://doi.org/10.7759/cureus.52723

[11] Li S, Pan W, Zhang M, Song K, Zhou Z, Zhao Q, Li G-Z, Zhu C. Chitosan-Based Dressing Materials for Burn Wound Healing. *Polymers*. 2025; 17(12): 1647. https://doi.org/10.3390/polym17121647

[12] Ahmed S, Ikram S. Chitosan and its derivatives: Applications in biomedical science. J Polym Environ. 2016; 24(3): 345-366.

[13] Bai Q, Zheng C, Chen W, et al. Current challenges and future applications of antibacterial nanomaterials and chitosan hydrogel in burn wound healing. Materials Advances. 2022; 3: 6707-6727. https://doi.org/10.1039/D2MA00695B