DECEMBER 11-12,2025
۲۱ و ۲۰ آذر ماه ۱۴۰۴
دومین کنگره پلاسما پزشکی ایران
The 2 nd Congress on Plasma Medicine
دبیرخانه دائمی کنگره پلاسما پزشکی ایران
www.plasmamedsym.ir

Integration of Cold Plasma with Post-Knee-Surgery Rehabilitation: Two-Dimensional Modeling of Dosimetry, Thermal Safety, and Antimicrobial Effect

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Citation:
Taftish F, Abrumand M. Integration of Cold Plasma with Post-Knee-Surgery ehabilitation: Two-Dimensional Modeling of Dosimetry, Thermal Safety, and Antimicrobial Effect. *Iran Biomed J*. Supplementary (2-2026): 3.

ABSTRACT

Introduction: Cold atmospheric plasma (CAP), through the generation of reactive oxygen and nitrogen species, can reduce infection at the incision surface and accelerate skin repair. This study, using a two-dimensional reaction–diffusion and heat-conduction model, provides a framework for CAP dosimetry and thermal safety in post-knee-surgery rehabilitation. It allows for the evaluation of microbial reduction and enhancement of epithelialization without exceeding the safe temperature range, providing groundwork for ex vivo and clinical validation.

Materials and Methods: The present study developed a two-dimensional finite-difference model to simulate the penetration of reactive species, heat conduction, and microbial-load reduction in the skin around the knee incision. The skin layers were modeled with distinct diffusion coefficients, applying a Dirichlet boundary condition for surface dosage, and a convective-flux boundary for heat transfer. Numerical simulations were performed using reference physiological parameters to evaluate thermal safety (≤33°C) and disinfection efficacy (up to 1.3-log reduction).

Results and Discussion: The results showed that reactive species penetrated to a depth of only 0.2 mm, the tissue temperature remained below 33°C, and the microbial load decreased by 0.59 log. A mild increase in dosage and exposure time, while staying within the safety limit, resulted in a microbial load reduction of 1–1.3 log.

Conclusion: At safe doses, cold plasma effectively reduces microbial load and facilitates the initiation of rehabilitation. Further ex vivo validation and clinical studies are needed to establish more accurate dose-response curves.

Keywords: Cold plasma, Microbial-load reduction, Post-surgical rehabilitation, Surgical wound, Thermal safety

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