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Tricalcium phosphate infused PMMA and Gelatin Membranes towards Wound Healing Applications

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Abstract
Wound healing represents a highly complex response in a living system to physical, chemical, mechanical and thermal injury. Biomaterials proven to be biocompatible to human tissues, flexible, stable and can be modified to act as a scaffold base. Aim of our study is to analyze the ability of tricalcium phosphate infused PMMA and Gelatin Membranes towards Wound Healing Applications. The 5% PMMA was dissolved in acetic acid with 100mg of tricalcium phosphate and shifted to a cold environment. preparation of the membrane 0.5% gelatin is dissolved in distilled water with 100mg of tricalcium phosphate, poured to 6 well plates and lyophilised to form the membrane. On SEM findings of pure PMMA membrane without damage, PMMA infused TCP showing presence of dispersed particles and Microscopical analysis showing pure porous gelatin membrane and TCP infused porous gelatin membrane with presence of particle.
The wound application aims for complete healing in a rapid manner, with functional and esthetic outcomes. In healthy individuals, infection is avoided by triggering the immune system, macrophage cells induce the migration to the wound site and then perform phagocytosis of pathogens. The present study demonstrates the uses of TCP infused PMMA and gelatin towards wound healing process through SEM analysis. Further investigation is required to formulate this into an effective wound healing application.
Keywords: wound healing, PMMA, gelatin, tricalcium phosphate, biomaterial, public health, health policy, health system, healthy lifestyle, medicine.

1. Introduction

Wound healing represents a highly complex response in a living system to physical, chemical, mechanical and thermal injury(1).(2) They involve cells, matrix components and other biological factors to act together in order to facilitate the healing and restore the tissue integrity. The wound healing process consists of phases such as homeostasis, inflammation, proliferation/granulation, and remodeling/maturation(3). The deficiency of normal healing can be caused by burns, infections, or even complications arising out of pathological states.
To aid the wound care and the healing process, a preferable wound dressing must be applied at the wound site to protect the injury site from further external microbial attack and mechanical stress(4). The regular wound dressings like cotton, bandages, and gauzes are dry and fail to provide a moist and active environment for proper wound healing(5). Moreover, due to wound drainage, dressings tend to stick to the wound bed, and at the time of removal cause pain for patients.(6) To deal with these limitations substantial efforts have been made to discover new protection that promotes wound healing and the repair of damaged tissue(7). Nanotechnology and tissue engineering provides various immense techniques in finding better wound applications.
Chronic and acute wounds remain a significant clinical challenge, particularly in patients with diabetes, vascular disorders, and traumatic injuries, where delayed healing can lead to infection, prolonged hospitalization, and increased healthcare costs.(8) Advanced biomaterials have emerged as promising strategies to enhance the natural healing cascade by providing structural support, maintaining a moist environment, and promoting cellular activities essential for tissue regeneration. Among these, polymethyl methacrylate (PMMA) and gelatin-based membranes have gained considerable attention due to their complementary properties.(9) PMMA is a biocompatible and mechanically robust synthetic polymer widely used in medical applications such as bone cements and prosthetics, while gelatin, a denatured derivative of collagen, offers excellent biodegradability, cell adhesion capability, and bioactivity that closely mimics the extracellular matrix.
Incorporating tricalcium phosphate (TCP), a bioactive and osteoconductive ceramic material, into PMMA and gelatin membranes further enhances their functional performance for wound healing applications. TCP is known for its biocompatibility, controlled biodegradation, and ability to release calcium and phosphate ions that stimulate cellular proliferation and tissue regeneration. When infused into polymeric matrices, TCP can improve mechanical strength, modulate degradation behavior, and provide bioactive cues that support angiogenesis and re-epithelialization. The synergistic integration of PMMA, gelatin, and TCP therefore presents a promising multifunctional wound dressing system that combines structural stability, biological activity, and regenerative potential. This composite approach holds significant promise for accelerating wound closure, minimizing complications, and advancing next-generation biomaterials for effective wound management.
Biomaterials such as gelatin is a natural polymer which can be derived from insoluble Collagen through hydrolysis is proven to be biocompatible to human tissues, flexible, stable and can be modified to act as a scaffold base(10). It comprises proline, glycine and hydroxyproline and is similar in the composition of amino acids. Human tissue has the ability to metabolize gelatin and it does not trigger any immune response in the human body. Polymethylmethacrylate (PMMA) has great mechanical properties, highly biocompatible, high hemocompatibility, low toxicity, non-biodegradable polymer which displays slow degradation making it better suited for biomaterial applications(11). Aim of our study is to analyze the ability of tricalcium phosphate infused PMMA and Gelatin Membranes towards Wound Healing Applications

2. Materials and methods:

2.1 Preparation of Tricalcium Phosphate–Infused PMMA Membrane

The tricalcium phosphate (TCP)–infused polymethyl methacrylate (PMMA) membrane was prepared using a solvent casting technique to ensure uniform dispersion of the bioactive ceramic phase within the polymer matrix. Briefly, 5% (w/v) PMMA powder was weighed and gradually added to acetic acid under continuous magnetic stirring to obtain a homogeneous polymer solution. Stirring was maintained until complete dissolution of PMMA to prevent the formation of aggregates and to achieve a clear, viscous solution. Subsequently, 100 mg of tricalcium phosphate powder was incorporated into the PMMA solution. The mixture was further stirred to ensure even distribution of TCP particles throughout the polymeric matrix, facilitating uniform bioactivity across the membrane.
The resulting composite solution was carefully poured into sterile Petri dish plates to achieve a consistent thickness. The plates were then transferred to a cold environment to allow slow solvent evaporation and controlled membrane formation. The low-temperature condition helped regulate solvent removal, minimizing bubble formation and structural irregularities. After complete solvent evaporation, a solidified PMMA-TCP membrane was formed. The dried membranes were gently peeled off from the Petri dishes and stored in a desiccator until further characterization and application in wound healing studies.

2.2 Preparation of Tricalcium Phosphate–Infused Gelatin Hydrogel Membrane

The hydrogel membrane was prepared using gelatin as a natural biopolymer matrix combined with tricalcium phosphate to enhance bioactivity. Initially, 0.5% (w/v) gelatin was dissolved in double-distilled water under constant stirring at an elevated temperature (typically 40–50°C) to ensure complete dissolution and formation of a uniform solution. Once the gelatin solution became clear and free of lumps, 100 mg of tricalcium phosphate powder was gradually added under continuous stirring to promote homogeneous dispersion within the polymer network.
The resulting mixture was allowed to stand overnight to ensure complete hydration of gelatin and uniform integration of TCP particles. After thorough mixing, the solution was poured into 6-well plates to achieve membranes of uniform size and thickness. The plates were then transferred to a deep freezer at –80°C to induce phase separation and solidification. Freezing at this temperature facilitates the formation of an interconnected porous structure within the hydrogel matrix. Following freezing, the samples were subjected to lyophilization (freeze-drying), which removed ice crystals through sublimation, resulting in a porous, sponge-like membrane structure.
The obtained TCP-infused gelatin membranes were carefully removed from the plates and stored under sterile conditions until further use. These membranes exhibit enhanced porosity, biodegradability, and bioactivity, making them suitable candidates for wound healing applications.

2. Results:

Our present study evaluates the effect of tricalcium phosphate infused PMMA and gelatin membrane towards wound healing process. In the study two different membranes were prepared using nanotechnology and infused with tricalcium phosphate and were analyzed under scanning electron microscope (SEM). SEM findings of pure PMMA membrane without damage (figure 1) and PMMA infused TCP showing presence of dispersed particles (figure 2). Microscopical analysis showing pure porous gelatin membrane (figure 3) and TCP infused porous gelatin membrane with presence of particle (figure 4).

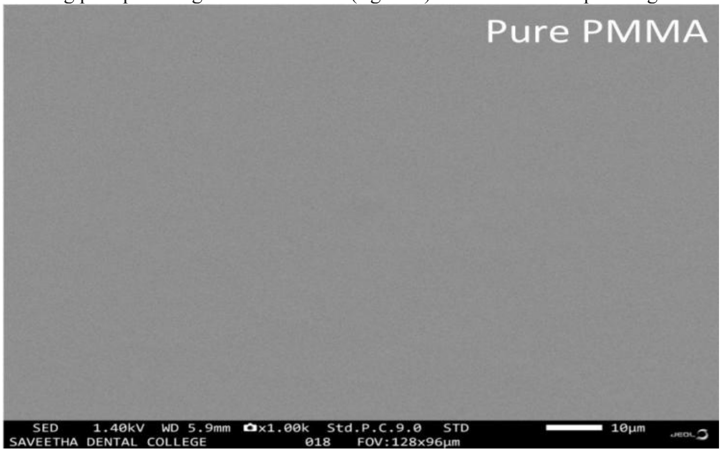

Figure 1: SEM findings of pure PMMA showing the membrane formed without damage and bubble formation

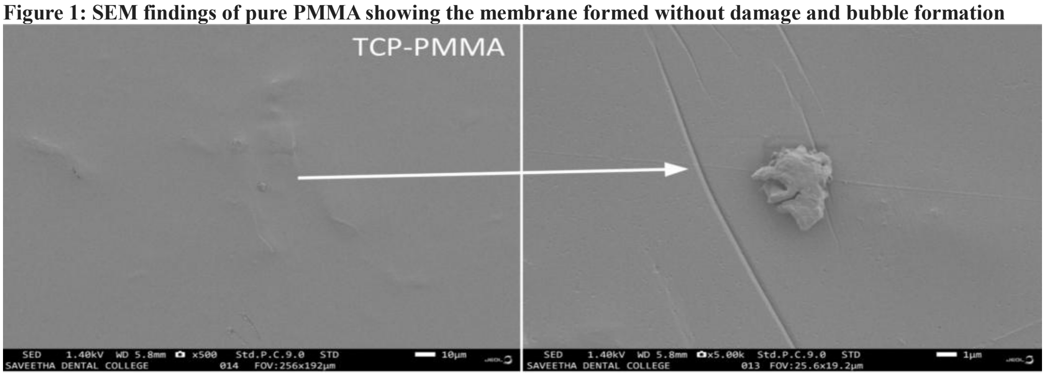

Figure 2: SEM findings of PMMA infused tricalcium phosphate showing presence of dispersed particle

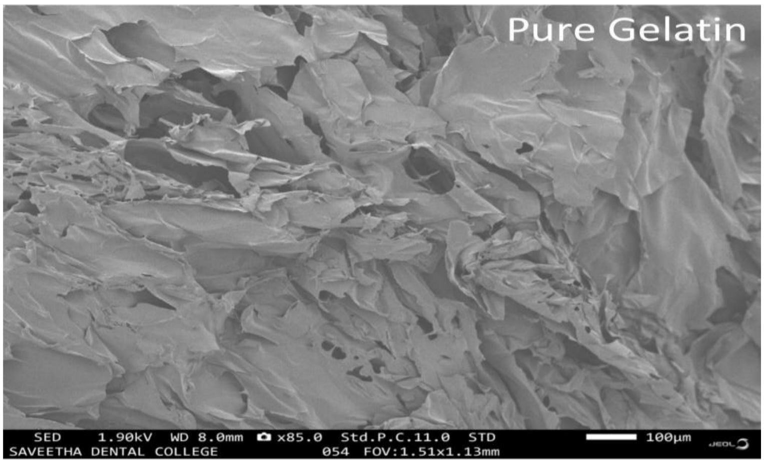

Figure 3: SEM analysis showing pure gelatin membrane with porosity

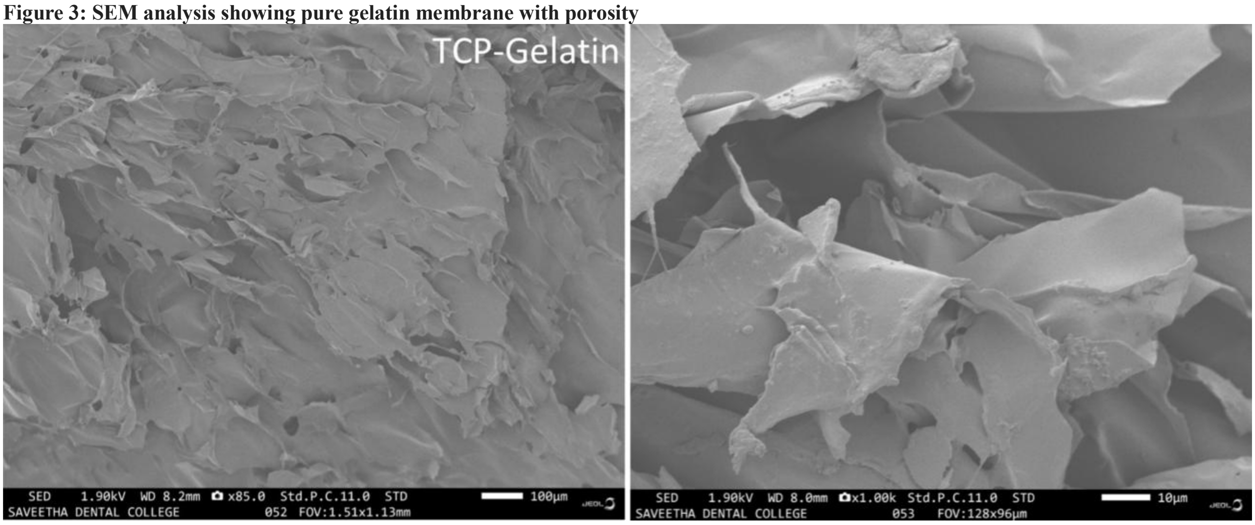

Figure 4: SEM analysis showing tricalcium infused porous gelatin membrane with presence of particle

4. Discussion:

Wound management primarily aims to achieve rapid and complete healing while restoring both functional integrity and aesthetic appearance of the affected tissue. Traditionally, wound care relied mainly on simple covering materials that played a passive role, serving only as protective barriers while the body carried out the natural healing process (Turabelidze and DiPietro 2013). Over time, advances in biomedical research and technology have significantly transformed this approach. A deeper understanding of the molecular and cellular mechanisms underlying wound healing has driven the development of more sophisticated and interactive wound dressings (Turabelidze and DiPietro 2013; Farina and Trombelli 2013). As a result, modern wound care strategies increasingly focus on multifunctional systems capable of actively participating in and enhancing the healing cascade (Larjava 2012).

The effectiveness of any wound healing application largely depends on the intrinsic properties of the materials used, including biocompatibility, biodegradability, mechanical strength, porosity, and bioactivity (Dogan 2019). Gelatin, a natural polymer derived from collagen, has gained attention in wound treatment due to its ability to support cell adhesion and mimic the extracellular matrix. However, previous studies indicate that gelatin-based wound treatment approaches are still at relatively premature stages and lack large-scale clinical validation. Recent advancements highlight the use of biomaterials in three-dimensional (3D) printing technologies to fabricate scaffolds that closely imitate the extracellular matrix, thereby enhancing tissue regeneration and structural organization (Kordestani 2019).

In healthy individuals, infection control is achieved through activation of the immune response, where macrophages migrate to the wound site and perform phagocytosis of invading pathogens while secreting growth factors essential for repair (Polverini 2013). Therefore, an ideal wound dressing must provide not only protection but also serve as a competent drug delivery platform capable of controlling therapeutic release in both spatial and temporal manners (Polverini 2013).

The present study focuses on understanding the potential of tricalcium phosphate–infused PMMA and gelatin membranes for wound healing applications, aiming to combine structural support with biological functionality (Polverini 2013; Kornsuthisopon, Tompkins, and Osathanon 2022).

Despite the promising properties of these materials, certain limitations remain. Rapid degradation of gelatin, particularly in colloidal solutions and at physiological temperature (37°C), continues to pose a challenge for sustained biomedical applications. With further optimization and comprehensive investigations, this composite system may be developed into an effective wound healing application.

5. Conclusion:

An ideal wound dressing should possess characteristics that enable it to effectively support and accelerate the natural healing process. It must be able to conform closely to the wound site, ensuring adequate coverage and intimate contact with the tissue surface. Proper conformity not only protects the wound from external contaminants but also helps maintain a moist microenvironment, which is essential for optimal cellular activity and tissue regeneration. In addition, an effective dressing should provide relief from pain and discomfort by minimizing mechanical irritation and shielding exposed nerve endings. By reducing inflammation and preventing secondary infection, such dressings can significantly promote faster wound-healing time and facilitate early restoration of the patient's normal daily activities, thereby improving overall quality of life.

The present study demonstrates the potential application of tricalcium phosphate (TCP)–infused PMMA and gelatin membranes in the wound healing process, as evidenced through scanning electron microscopy (SEM) analysis. The SEM observations provide insights into the surface morphology, porosity, and distribution of TCP particles within the polymeric matrices. These structural characteristics are crucial, as surface architecture and pore interconnectivity directly influence cell attachment, proliferation, and nutrient exchange at the wound site. The incorporation of TCP within PMMA and gelatin matrices may enhance bioactivity and provide a supportive framework for tissue regeneration.

However, further investigation is required to optimize material composition, mechanical stability, degradation behavior, and biological performance before translating this composite system into a clinically effective wound healing application. Comprehensive in vitro and in vivo studies will be necessary to validate its safety, efficacy, and long-term therapeutic potential.

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Conflict of interest

The authors would like to declare no conflict of interest in the present study.

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