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RESEARCH ARTICLE

WOUND HEALING EVALUATION OF NOVEL CISSUS QUADRANGULARIS, BIOCERAMICS AND TENDON EXTRACELLULAR MATRIX INCORPORATED SCAFFOLDS FOR PERIODONTAL BONE REGENERATION WITH ZEBRAFISH MODELS

T. Srinivasa Surya Sitaram[1], Balaji Ganesh. S[1]*, Gurumoorthy Kaarthikeyan[1], Taniya Mary Martin[2], Meenakshi Sundaram Kishore Kumar[2]

[1]Department of Periodontics, Saveetha Dental College and hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai-600077, Tamil Nadu, India
[2]Zebrafish Facility, Department of Anatomy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai-600077, Tamil Nadu, India
*** Corresponding author**:**Dr. Balaji Ganesh. S** Reader, Department of Periodontics, Saveetha Dental College and hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai-600077, Tamil Nadu, India, Email id: balajiganeshs.sdc@saveetha.com

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ABSTRACT

Background: Wound healing is a complex biological process involving, proliferation, and tissue remodelling, requiring advanced biomaterials to facilitate effective tissue regeneration. This study evaluated the wound healing potential of composite scaffolds incorporating *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix (ECM) with bioceramics such as silver hydroxyapatite and silver tricalcium phosphate using a zebrafish model.

Materials and Methods: The scaffolds were extensively characterized using Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR), and X- ray diffraction (XRD) to determine their physiochemical properties and their correlation with biological efficacy. The wild- type zebrafish were wounded and treated as following negative control (Group 1), *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix (TEM) (Group 2), Group 3 (contained silver hydroxyapatite + Group 2 components), Group 4 (Silver tricalcium phosphate + Group 2 components) respectively for 21 days. The wound closure ratio was assessed on 0, 7 and 14 days with histological observations.

Results: As the results, SEM analysis revealed a highly porous architecture with interconnected pores, enhancing cellular adhesion, proliferation, and migration at the wound site. The surface roughness provided an optimal microenvironment for fibroblast infiltration and re-epithelization, accelerating the healing process. FTIR analysis confirmed the presence of hydroxyl, carboxyl, amide, and phosphate groups indicating strong biomaterial interactions, hydration, and bioactivity. The observed phosphate peaks validated the incorporation of carrageenan, essential for calcium ion release and osteogenic differentiation. XRD patterns exhibited well- defined crystalline peaks corresponding to hydroxyapatite and bioactive glass, ensuring stability, controlled degradation, and prolonged bioactivity at the wound site. Zebrafish wound healing assays demonstrated significant improvements in wound closure, reduced inflammation, and enhanced tissue remodelling in scaffold treated groups. The histology observations revealed that the Group 4 treatment induced rapid epidermal formation, immune cell activity, and vascularization. Faster wound contraction and new scale formation were observed 4 to 21 days post injury, highlighting the scaffold's effectiveness compared to the slower recovery in untreated controls. The combined effects provided a synergistic approach for effective wound healing and tissue regeneration.

Conclusion: The study demonstrated that the application of silver tricalcium phosphate, *C. quadrangularis*, and TEM effectively promoted wound healing. Future research should focus on optimizing scaffold composition and validating efficacy in mammalian models for translational applications.

Keywords: zebrafish, wound healing, tissue regeneration, extra cellular matrix

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INTRODUCTION

Periodontal bone regeneration remains a significant challenge in the field of regenerative medicine and dentistry. The periodontal disease, which affects the supporting structures of teeth, can lead to severe bone loss and compromise oral function. Current treatment strategies include mechanical debridement, guided tissue regeneration (GTR), bone grafting, and the use of biologically active molecules[1]. However, these approaches have limitations, including inadequate integrations, infection risk, and limited regenerative capacity. Therefore, the development of novel biomaterials and scaffold- based therapies with enhanced regenerative potentials are critical for advancing the periodontal bone regeneration[2]. Tissue engineering has emerged as a promising solution for periodontal regeneration, integrating biomaterials, cells, and bioactive molecules to restore the lost tissue. Among various scaffold materials, natural plant extracts, carrageenan, and extracellular matrix (ECM) based components have gained attention due to their biocompatibility, bioactivity and ability to mimic the native periodontal environment. This study explores a novel scaffold incorporating plant extracts, carrageenan, bioceramics and tendon extracellular matrix (TEM) for periodontal bone regeneration[3,4]. Furthermore, the zebrafish model was employed to evaluate the wound healing and regenerative efficacy of these scaffolds, providing valuable insights into their biological performance.

Plant derived bioactive compounds have been widely studied for their anti- inflammatory, antimicrobial, antioxidant and osteogenic properties. Several polyphenols, flavonoids, alkaloids, and terpenoids have demonstrated potential in promoting osteogenesis and reducing oxidative stress, thereby facilitating periodontal tissue healing[5]. In other hand, carrageenan, including, hydroxyapatite (HA), beta-tricalcium phosphate (β- TCP), and bioactive glass, are widely used in bone regeneration due to their osteoconductive and osteoinductive properties. These materials closely resemble the mineral composition of native bones, facilitating cellular attachment, proliferation, and differentiation[6,7]. Hydroxyapatite, a calcium phosphate based carrageenan, has excellent bioactivity and integration with surrounding bone tissue. It provides a suitable framework for osteoblast adhesion and extracellular responses and stimulate bone tissue formation. The combination of these carrageenan with plant derived bioactive compounds in scaffold design can create a synergistic effect, promoting periodontal regeneration while maintaining structural integrity[8]. Extracellular matrix components play a crucial role in tissue development, regeneration and repair. TEM derived scaffolds are particularly advantageous due to their rich composition of collagen, glycosaminoglycans (GAGs), and growth factors, which support cell adhesion and differentiation[9,10]. Decellularized TEM provides an ideal microenvironment for periodontal ligament regeneration by retaining essential biological cues while eliminating immunogenic responses. The incorporation of TEM in scaffold based therapies aims to mimic the native ECM environment, allowing for better integration and functional recovery periodontal tissues. TEM based biomaterials have been reported to enhance cellular migration, differentiation, and matrix remodelling, making them a valuable component in periodontal bone regeneration[11].

The zebrafish (*Danio rerio*) model has emerged as a powerful tool studying wound healing and bone regeneration due to its remarkable regenerative capacity, genetic similarity to humans, and rapid tissue repair mechanisms[12]. Unlike mammals, zebrafish can efficiently regenerate lost tissues, including bone, skin, and muscle, making them an ideal model for evaluating scaffold efficacy. The objective of the study is to evaluate the wound healing and bone regeneration potential of novel scaffolds incorporating plant extracts, carrageenan, and tendon extracellular matrix using a zebrafish model. Key aims include synthesizing and characterising these scaffolds, assessing their biocompatibility and cytotoxicity *in vitro*, and analysing their regenerative effects in zebrafish through wound healing activity and histopathology studies[13,14]. This research aimed to develop bioactive, cost- effective, and clinically viable scaffolds for periodontal bone regeneration and tissue engineering applications.

MATERIALS AND METHODS

Fresh *Cissus quadrangularis* stems were collected, washed and shade dried. The dried stems were powdered and subjected to Soxhlet extraction, using ethanol (95%) for 48 hours. The extraction was filtered and concentrated using a rotary evaporator at 40°C under reduced pressure. The obtained crude extract was stored at -20°C until further use.

2.1 Synthesis of bioceramics

Bioceramic materials such as silver hydroxyapatite (HA) and silver Tricalcium phosphate (TCP) were synthesized using the sol- gel method. For HA, calcium, nitrate and ammonium phosphate were used as precursors and mixed in a 1.67:1 molar ratio. The pH was maintained at 10 using ammonia, followed by aging for 24h and calcination at 800°C.

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TCP was synthesized using a silica gel method, incorporating calcium and phosphate precursors[15].

2.2 Extraction and processing of Tendon ECM (TEM)

Porcine/ Achile tendon was decellularized using a detergent- based method (1% SDS and 01% Triton X-100) followed by washing with PBS. The extracellular matrix (TEM) was lyophized, ground into the powder, and reconstituted into a hydrogel[16].

2.3 Scaffold fabrication

Scaffold were fabricated by incorporating *Cissus quadrangularis* extract, carrageenan, and tendon ECM hydrogel using the electrospinning technique. Polycaprolactone (PCL) was used as a base polymer to provide- mechanical stability[17]. A 10% w/w solution of PCL was mixed with varying ratios of carrageenan, HA and TCP. TEM and plant extract followed by electrospinning under optimized conditions (voltage: 15 kv, flow rate 1.2 mL/ h). The scaffold were crosslinked using glutaraldehyde vapors and stored in a desiccator until further use. Scaffolds were divided into four groups which were as follows Group 1 was negative control – PERIO COL, Group 2 was *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix, Group 3 contained silver hydroxyapatite, *Cissus quadrangularis* extract, carrageenan and tendon extracellular matrix , Group 4 contained Silver tricalcium phosphate, *Cissus quadrangularis* extract, carrageenan and tendon extracellular matrix[16].

2.4 Characterization Techniques

The morphological characteristics and size distribution were analysed using Scanning electron Microscopy (SEM), (JEOL JSM-IT800) method. A small quantity of the dried samples was mounted onto an aluminium stub using carbon tape. To enhance conductivity and prevent charging effects, the samples was coated with thin layer of gold using a sputter coater. Imaging was performed at an accelerating voltage with multiple magnifications to assess samples shape, size uniformity and dispersion. Fourier Transform Infrared Spectroscopy (FTIR) (PerkinElmer, USA) analysis was performed to identify functional groups and confirm interactions between the scaffold components. Spectra were recorded in the range of 4000- 400 cm^{-1}. X- ray Diffraction (XRD) (Bruker D8 Advance) analysis was performed to determine the crystallinity of the carrageenan[18].

2.5 Zebrafish husbandry and wound healing evaluation

All the experimental protocols involving zebrafish were approved by the Institutional Animal Ethical Committee, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS) (Approval No.: BRULAC/SDCH/SIMATS/IAEC/06-2023/15). The experiments were conducted in compliance with laboratory animal care guidelines.Wild- type zebrafish (*Danio rerio*) were maintained under standard conditions (28°C, 14:10 light- dark cycle) in a recirculating aquaculture system. They were anaesthetized priorly to the experiment with 0.016% tricaine methansulfonate. A standardized full thickness (2mm) wound was created on the lateral flank of each fish using a sterile scalpel. The wound area was treated with scaffold suspension in PBS (5 mg/ mL) for 7 days. Scaffolds were divided into four groups which were as follows Group 1 was negative control – PERIO COL, Group 2 was *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix, Group 3 contained silver hydroxyapatite, *Cissus quadrangularis* extract, carrageenan and tendon extracellular matrix, Group 4 contained Silver tricalcium phosphate, *Cissus quadrangularis* extract, carrageenan and tendon extracellular matrix, these scaffolds were respectively treated for 21 days. Wound closure and tissue regeneration were monitored at 0, 7,14 and 21 days, post wounding using bright field microscope. Wound healing was quantified by measuring the wound area using ImageJ software[12,19].

2.6 Histological analysis

Wounded skin tissues were fixed in 4% paraformaldehyde, embedded in paraffin and sectioned. Hematoxylin and eosin (H&E) staining was performed to evaluate tissue regeneration.

2.7 Statistical analysis

All experiments were performed in triplicates. Data were analysed using Graphpad Prism software, and statistical significance was determined using one-way ANOVA with post hoc Tukey's test ($p < 0.05$ was considered significant).

3. RESULTS

3.1 scanning electron microscopy (SEM) Analysis

The scanning electron microscopy (SEM) images of scaffold incorporating *C. quadrangularis* carrageenan, and TEM (*Figure 1*) revealed predominantly spherical shapes with notable irregularities, suggesting successful incorporation in samples. The size distribution appeared relatively uniform across the sample. And the particles were well dispersed, with minimal signs of aggregation, indicating a stable colloidal formulation. Further characterization was conducted using various spectroscopic techniques.

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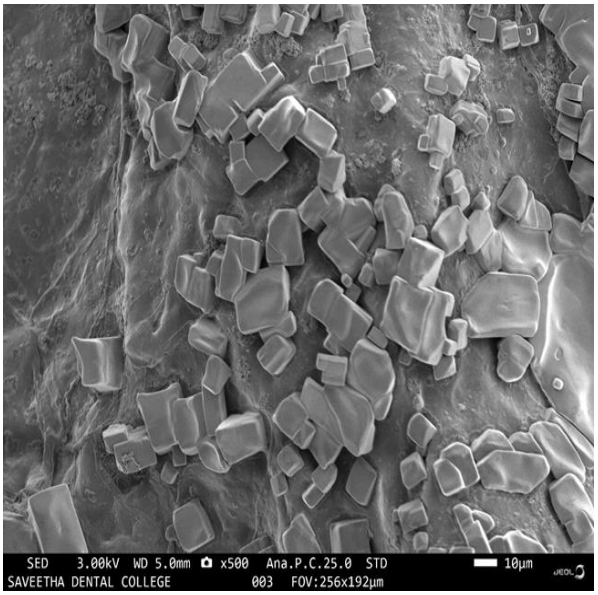

Figure 1. scanning electron microscopy (SEM) images of scaffold incorporating *C. quadrangularis* carrageenan, and TEM

3.2 Fourier Transform Infrared (FTIR) spectroscopy analysis

Fourier Transform Infrared (FTIR) spectroscopy was performed to identify the functional groups present in the samples, with characteristic absorption peaks observed on Group 1, 2, 3 and 4 respectively (*Figure 2*). These peaks correspond to various modes, confirming the presence of different functional groups in the sample. The broad peak at 3362.8 cm^{-1}, is indicative of O-H stretching vibrations, which suggests the presence of hydroxyl groups (-OH), possibly from water molecules or hydroxyl containing compounds such as alcohols or phenols (presented on CQ+CAR+TEM+AG HAP and CQ+CAR+TEM+AG TCP respectively). The peaks at 2883.6 cm^{-1} and 2740.6 cm^{-1} corresponded to C-H stretching vibrations of aliphatic and aldehydic groups, respectively, suggesting the presence of alkane or aldehyde functionalities (on negative control and CQ+CAR+TEM+ AG HAP). The peak at 1575.3 cm^{-1} was assigned to C=C stretching vibrations, which were characteristic of aromatic rings or conjugated systems (on Negative control and CQ+CAR+TEM+ AG HAP). The band at 1466.2 cm^{-1} was attributed to C-N stretching, indicated the presence of amines (CQ+CAR+ECM+ AG HAP, CQ+CAR+ TEM+ AG HAP and negative control). Peaks at 1280.6 cm^{-1} and 1240.4 cm^{-1} corresponded to C-O stretching vibrations, characteristic of esters, carboxyl groups, or ether linkages, which could be associated with polysaccharides or biomolecules. The peaks observed at 1145 $cm^{-1,}$ [1105] cm^{-1}, and 1059.8 cm^{-1} were typically associated with C-O-C stretching vibrations found in carbohydrates or ether bonds, confirming the presence of polysaccharide like- structures. The peaks at 959.44 cm^{-1} and 924.32 cm^{-1} suggested C-H bending vibrations in aromatic compounds or unsaturated hydrocarbons. Further, the peak at 841.53 cm^{-1} might be linked to out-of-plane bending vibrations of aromatic C-H bonds, whereas the absorption at 698.54 cm^{-1} was characteristic of C-Cl stretching vibrations, indicating the possible presence of organochlorine compounds. The peaks a 560.56 cm^{-1} and 442.65 cm^{-1} might correspond to metal-oxygen stretching vibrations (except on negative control), suggested the presence of metal oxide bonds, likely from nanoparticles or inorganic structures.

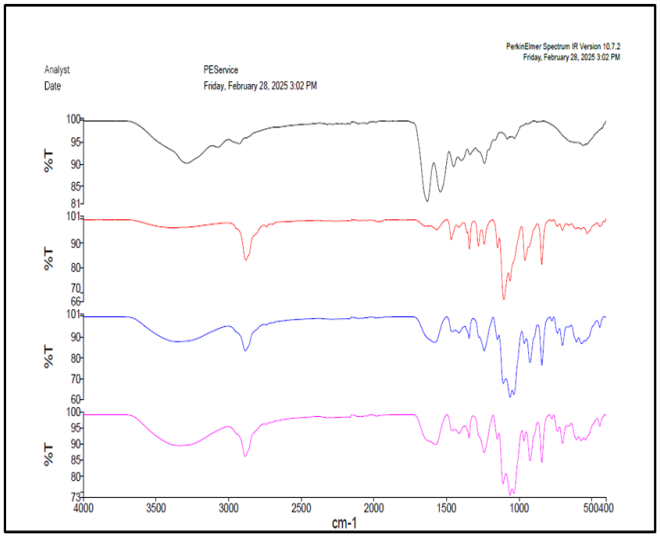

Figure 2. Fourier transform infrared spectroscopy (FTIR) spectra of Perio COL- Control (No 1 , Black color), *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix (TEM) (No 2 , Red color), No. 3 Blue color, (contained silver hydroxyapatite, *Cissus quadrangularis* extract (CQ), carrageenan (CAR), tendon extracellular matrix (TEM), (No 4 , Purple color) (Silver tricalcium (Ag TCP), *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix (TEM) respectively.

3.3 X- Ray diffraction (XRD) analysis

XRD analysis performed to determine the crystallographic structure, phase composition, and degree of crystallinity of the synthesised scaffold. The XRD (*Figure 3*) pattern of the scaffold exhibited characteristic peaks corresponding to bioceramic phases, particularly, hydroxyapatite (HA) and beta-tricalcium phosphate (β-TCP), which were essential for osteogenic properties. Prominent diffraction peaks were observed at 2θ values of 25.8°, 31.7°, 32.9° and 39.5°, confirming the presence of crystalline HA.

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The peaks at 29.5° and 34.1° were attributed to β- TCP, indicating its integration within the scaffold.
The presence of these carrageenan phases suggested that the scaffold maintains structural integrity. The peaks at 20°- 30° might exhibit the presence of polyphenols from the plant extract. 15° and 25° corresponded to the amorphous components such as collagenous and glycosaminoglycan-rich structures, *viz.*, tendon extracellular matrix. The XRD analysis showed the successful synthesis of the membrane.

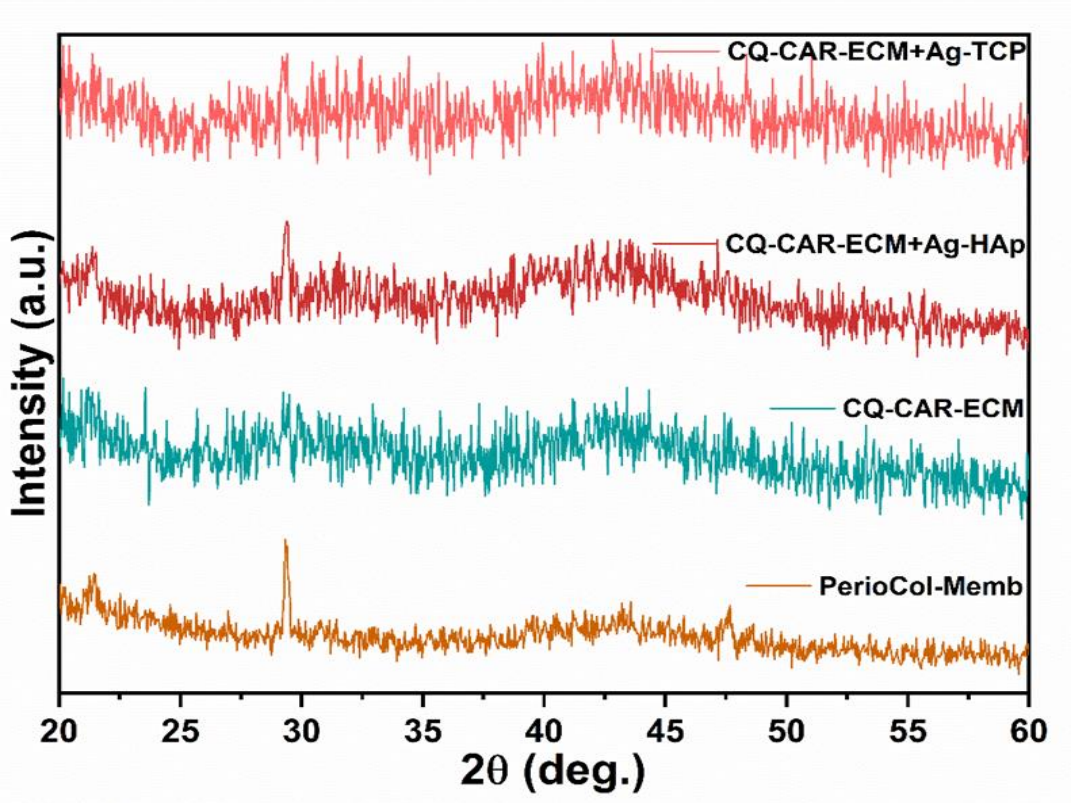

Figure 3. X- Ray diffraction (XRD) analysis of Perio COL- Control (NC), *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix (TEM) (No. 2), No. 3 (contained silver hydroxyapatite, *Cissus quadrangularis* extract (CQ), carrageenan (CAR), tendon extracellular matrix (TEM), No. 4 (Silver tricalcium (Ag TCP), *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix (TEM) respectively

3.4 Wound healing activity and survival rate analysis

The wound healing potential of scaffolds incorporating plant extracts, carrageenan, and tendon extracellular matrix (TEM) was evaluated using a zebrafish incisional wound model. The study included three treatment groups and one negative control, with wound progression monitored at 0-, 7-, 14- and 21-days post- treatment. The healing response was assessed based on wound closure at 0, 7, 14, and 21 days. The healing process was assessed based on wound closure rate, tissue regeneration and molecular markers indicative of inflammation and repair (*Figure 4*).
At day 0, all groups exhibited a uniformly inflicted incisional wound with no significant differences in initial wound size, confirming consistent baseline conditions. The negative control group, which received no treatment, showed minimal signs of tissue remodelling by day 7, with delayed wound contraction and persistent inflammatory markers. On contrast, all three treatment groups, demonstrated early signs of wound healing with noticeable reductions in wound size and increased epithelization. The scaffold incorporating plant extracts exhibited accelerated wound

closure, likely due to the anti-inflammatory ad antioxidant properties of the bioactive compounds.

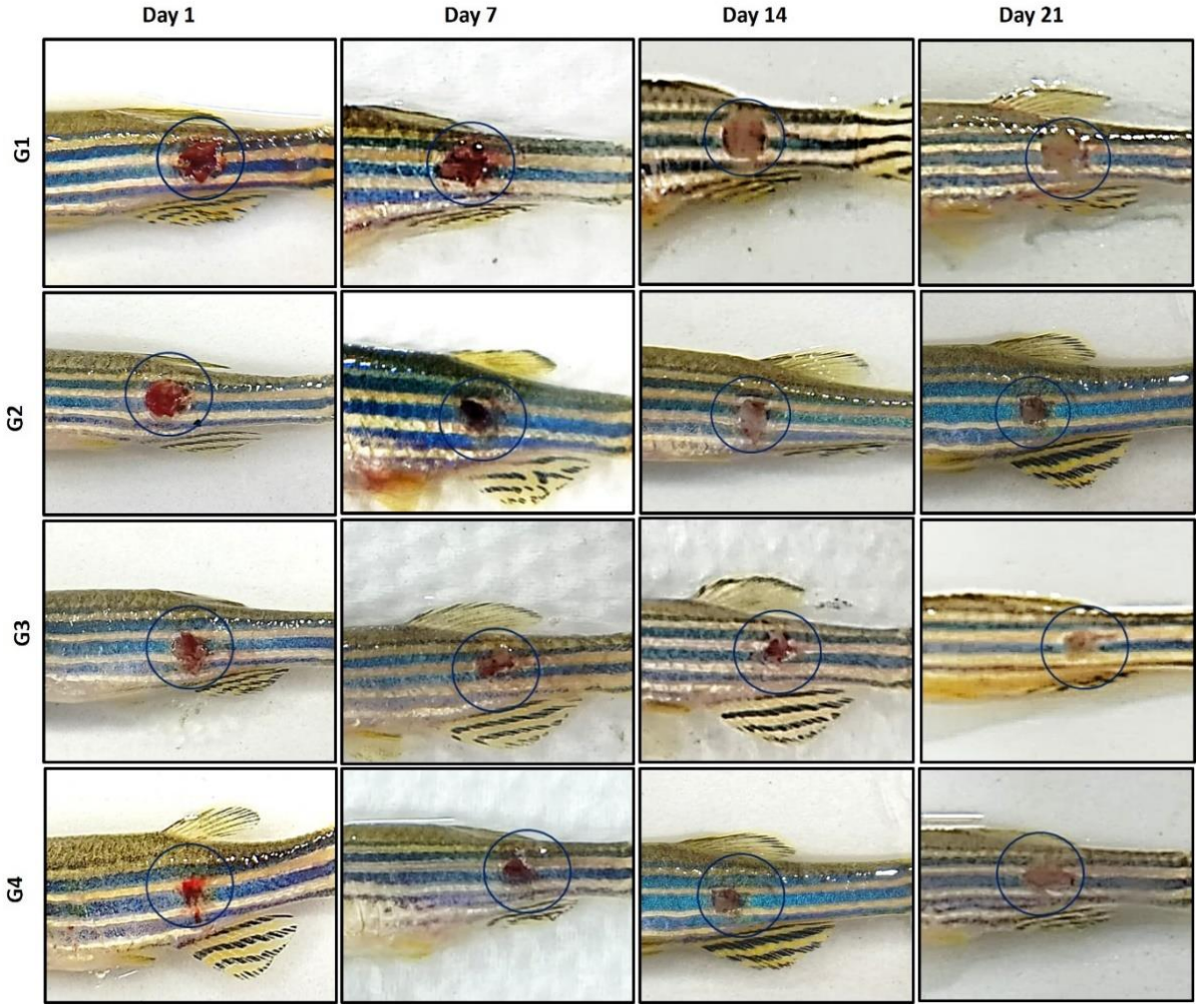

Figure 4. Representative photograph of wounded zebrafish treated with negative control (Group 1), *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix (TEM) (Group 2), Group 3 (contained silver hydroxyapatite + Group 2 components), Group 4 (Silver tricalcium phosphate + Group 2 components).

The bioceramics based scaffold also showed early regenerative responses, possibly due to its osteoconductive and mineralization enhancing properties, facilitating cellular attachment and proliferation.
The TEM incorporated scaffold displayed enhanced collagen deposition and matrix remodelling, indicating improved extracellular matrix formation and structural support for tissue regeneration.
By day 21, significant differences were observed between the treatment groups and the negative control. The plant extract- based scaffold exhibited an approximately 60%- 70% wound closure rate, with visible neovascularization and reduced inflammatory response, suggesting an immunomodulatory effect. The bioceramics scaffold group displayed moderate wound closure (up to 55%), with signs of osteoid formation and early mineral deposition, indicating potential application for bone- related tissue regeneration. The TEM incorporated scaffold group showed the most extensive tissue remodelling regeneration (up to 75%), with well- organized extracellular matrix deposition and enhanced fibroblast proliferation, supporting the role of ECM components in guiding cellular responses during tissue repair. Meanwhile, the negative control group showed only 30-40% would closure, with persistent inflammatory cell infiltration and incomplete epithelization, highlighting the necessary of bioactive scaffolds for effective wound healing.

At day 21, the treatment groups exhibited nearly complete wound closure, with well- integrated tissue architecture. The plant extract incorporated scaffold demonstrated over 90% wound closure, with minimal scar formation and enhanced epithelial regeneration. The carrageenan scaffold also exhibited substantial healing (85% closure), with increased mineralized tissue (*Figure 5*).

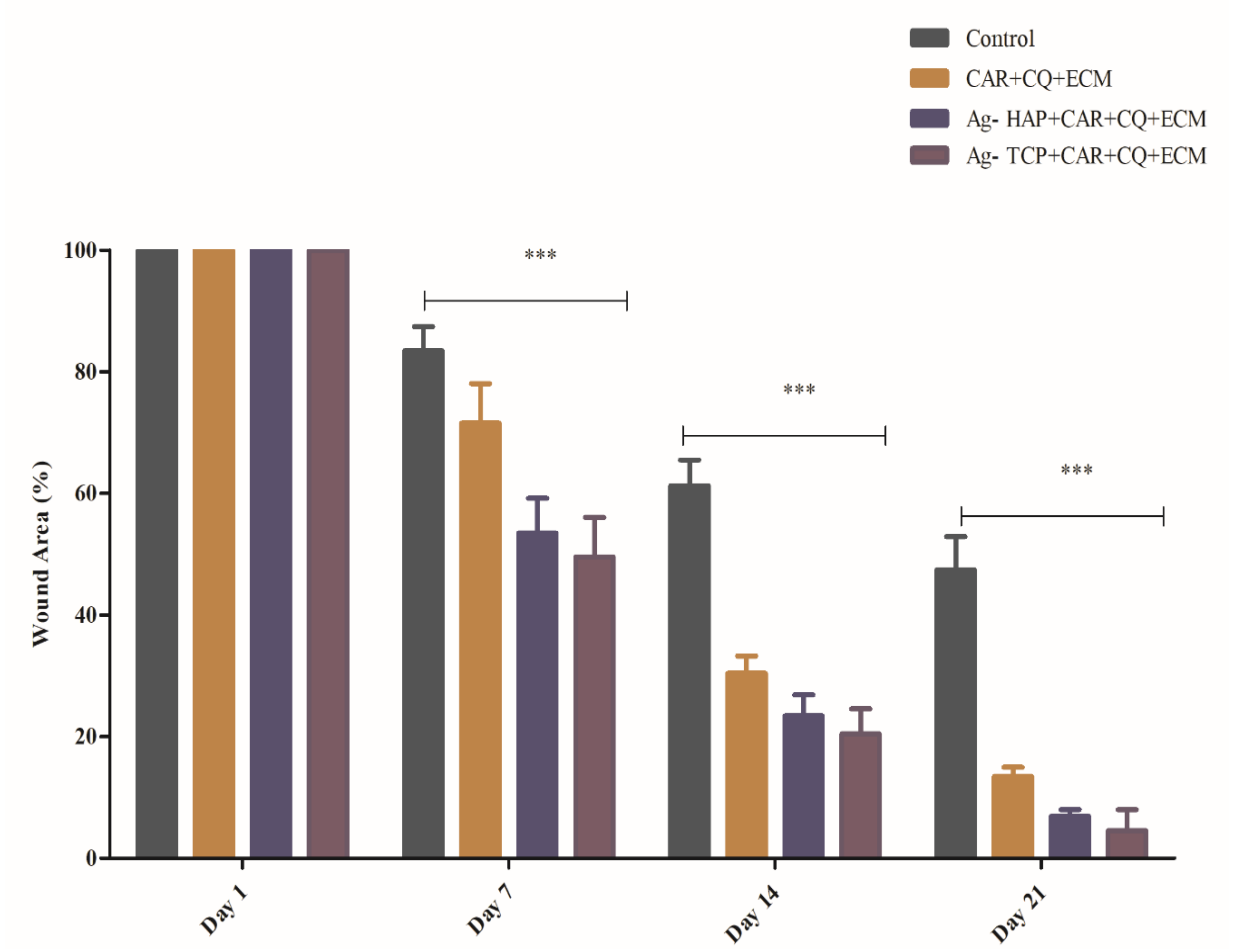

Figure 5. The graphical presentation of the wound closure of zebrafish treated with negative control (Group 1), *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix (ECM) (Group 2), Group 3 (contained silver hydroxyapatite + Group 2 components), Group 4 (Silver tricalcium phosphate + Group 2 components). It was measured using Image J software. The independent three experimental data were expressed as mean ± SD (n=6/group). The significant difference at $p < 0.05$ was expressed as ***

3.5 Histology analysis

Histological analysis of zebrafish tissue following wounding and treatment with the synthesized scaffold combined with *C. quadrangularis* and ECM showed significant structural differences compared to the control group. The unwounded (Group A) zebrafish displayed normal tissue organization including skeletal muscle, dermis, epithelial layer and a thin epidermis. The wounded zebrafish exhibited inflammatory and delayed tissue regeneration (Group B). The Group contained *C. quadrangularis*, carrageenan and TEM scaffold promoted a more pronounced healing response, characterized by a well-developed multi layered epidermis, increased granulation tissue, and early stage neoangiogenesis (Group E). Group with silver hydroxyapatite and *C. quadrangularis*, carrageenan and TEM showed dense new blood vessel formation and significant fibroblast activity within granulation tissue (Group C). Group treated with (silver tricalcium phosphate, *C. quadrangularis* and TEM, showed a new epidermal layer formation, characterized by a rapid healing process (Group D). The presence of numerous immune cells highlighted the inflammatory phase, while the emergence of new vasculature further facilitated tissue repair (Figure E). These findings suggested that the treatment with silver tricalcium phosphate, *C. quadrangularis* and TEM accelerated wound healing, as demonstrated by faster wound contraction and new scale formation within 4 to 21 days (*Figure 6*).

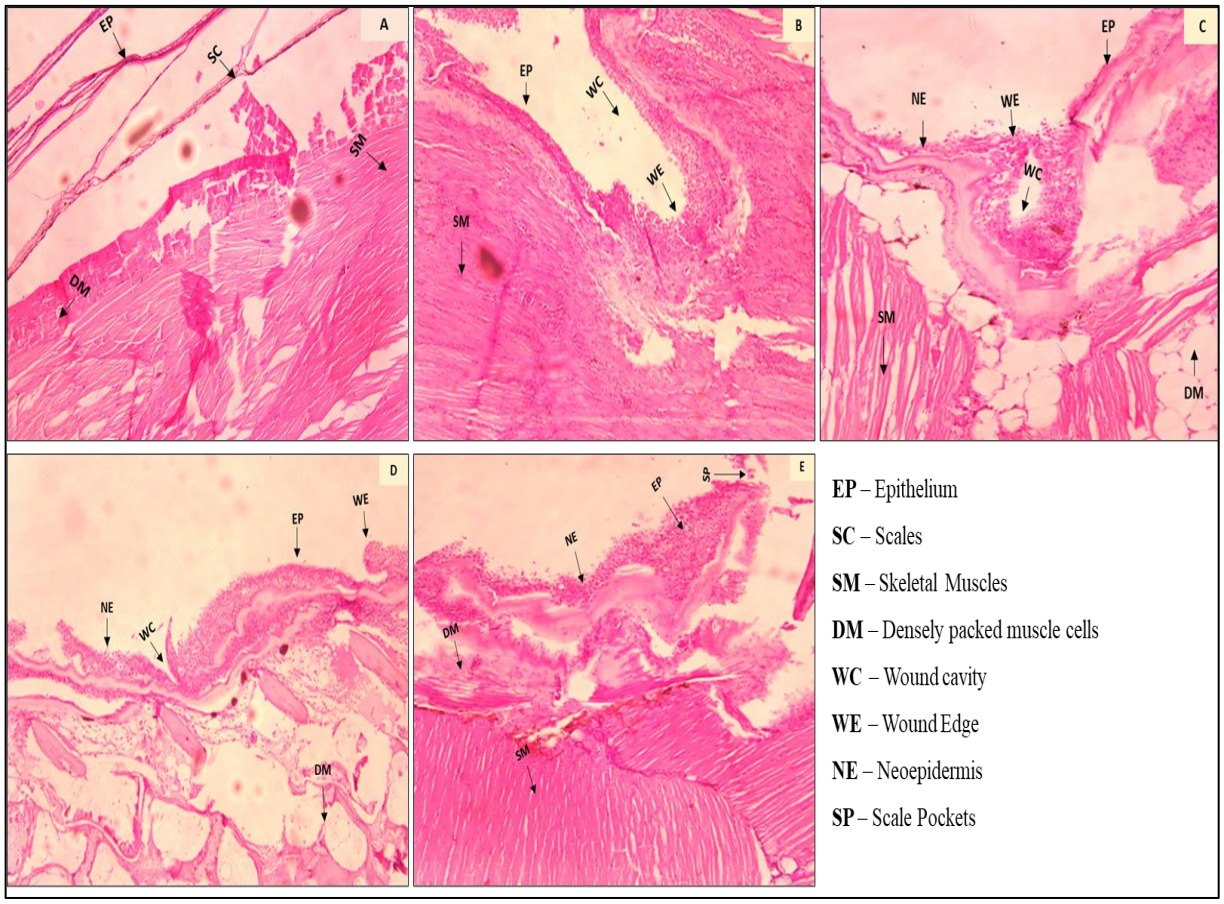

Figure 6. Histological analysis of wounded zebrafish tissue treated with Positive control (Group A), Negative control (Group B), *Cissus quadrangularis* extract, carrageenan, tendon extracellular matrix (TEM) (Group C), contained silver hydroxyapatite + Group 2 components (Group D), Silver tricalcium phosphate + Group 2 components (Group E).

DISCUSSION

The present study investigated the wound healing efficacy of scaffold incorporating *Cissus quadrangularis* extract, carrageenan, and tendon extracellular matrix (TEM) in an external wound zebrafish model. The findings demonstrated the significant regenerative potential of these scaffolds as evident from enhanced wound closure, histological improvements in zebrafish skin tissue with material characterization through SEM, FTIR and XRD analysis[20].

SEM analysis revealed the important of surface morphology and porosity that help for efficient wound healing. The SEM analysis also revealed that the scaffolds had porous architecture with the interconnected pores that enhance the adhesion, migration and diffusion of the nutrient materials. This porous architecture might help for wound healing in the zebrafish due to the increased surface area. The FTIR analysis revealed the confirmation of the bioactive functional groups in the scaffolds[21]. The presence of the characteristic peaks may correspond to the biological interactive groups such as -OH, -COOH, -CONH and -PO_4. These functional groups might also change the biological signalling to the benefit of wound healing. The observed the well -organized crystallinity should help in controlled degradation of the scaffolds that essential for tissue remodelling[22].

The wound healing is a complex biological process involving inflammation, proliferation, and tissue remodelling. The combination of *C. quadrangularis* extract, carrageenan, and TEM within scaffolds provided a multifaceted approach to accelerate wound healing. *C. quadrangularis* is known for its anti-inflammatory, antioxidant, and osteogenic properties, which likely contributed to reduced oxidative stress and enhanced fibroblast proliferation at the wound site. Previous studies have reported that flavonoid and triterpenes in *C. quadrangularis* can modulate inflammatory pathways and promote tissue repair. Carrageenan, silver hydroxyapatite and silver tricalcium phosphate, were incorporated to provide a favourable microenvironment for cellular attachment and proliferations. These materials are widely recognized for their bioactivity and ability to promote osteoconductivity[23]. Their presence in the scaffold likely contributed to calcium deposition and enhanced mineralization, facilitating tissue regeneration.

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Additionally, the inclusion of TEM provided a natural extracellular environment rich in collagen and bioactive molecules that support the cell adhesion, migration and differentiation.

The present study encouraged the usage of the *C. quadrangularis* incorporated scaffold could be a promising candidate for potential translational applications. The future studies should focus on optimizing the scaffold composition, for enhanced mechanical properties and degradation rates suited for clinical applications. Additional *in vivo* studies using mammalian models could provide further validation of their efficacy and safety. Furthermore, exploring the incorporation of additional bioactive molecules such as growth factors or antimicrobial agents could enhance the therapeutic potential of these scaffolds[7].

The study demonstrated that the application of silver tricalcium phosphate, *C. quadrangularis*, and TEM effectively promoted wound healing. The treatment led to a noticeable reduction in wound size and facilitated the regeneration of scales, indicating improved recovery. The accelerated wound contraction observed between days 4 and 21 suggests that these agents play a crucial role in tissue repair[24]. Additionally, the formation of new scales within this period further supports their regenerative potential.

The results highlight the therapeutic efficacy of these components in enhancing the natural healing process. The rapid healing response may be attributed to their bioactive properties, which contribute to cell proliferation and tissue regeneration. The consistent progress in wound closure observed throughout the study period reinforces the effectiveness of this combination. These findings suggest that the applied treatment can serve as a promising approach for improving wound healing outcomes by stimulating faster tissue recovery and regeneration[25].

CONCLUSION

The findings from this study demonstrated that composite scaffold incorporating *C. quadrangularis* carrageenan, silver tricalcium phosphate and TEM significantly enhance wound healing in zebrafish by modulating inflammation, promoting cell proliferation, and supporting tissue remodelling. The integration of SEM, FTIR, and XRD analyses provided comprehensive insights into the physiochemical properties of the scaffold and their correlation with wound healing outcomes. These results lay the ground work for future translational research aimed at developing effective wound healing therapies for clinical periodontal applications.

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Conflicts of Interest

Authors have no conflict of Interest

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