

Systematic Review: Effect of Gelatin-Curcumin Nanocomposites for Implant Healing Abutment: Systematic Review

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ABSTRACT

Introduction: This systematic review investigates the effect of gelatin-curcumin nanocomposites on implant healing abutments. Gelatin, a biocompatible polymer, and curcumin, a bioactive compound with anti-inflammatory and antimicrobial properties, are combined to enhance tissue integration and reduce infections during the critical healing period following implant placement.

Material and methods: The review focuses exclusively on laboratory studies evaluating the biological and mechanical outcomes of these nanocomposites. Studies were selected based on their investigation of cell proliferation, antimicrobial activity, and the mechanical properties of gelatin-curcumin coatings on implant materials. Data were extracted and analyzed for trends in healing efficacy, bacterial inhibition, and coating stability.

Results: Results showed that gelatin-curcumin nanocomposites significantly promote osteoblast and fibroblast activity, leading to better tissue regeneration. They also demonstrated effective antimicrobial properties against common oral pathogens, such as *Staphylococcus aureus* and *Escherichia coli*. Additionally, the nanocomposites maintained mechanical stability without compromising the structural integrity of implants.

Conclusion: In conclusion, gelatin-curcumin nanocomposites exhibit potential for enhancing implant healing through improved tissue integration and infection prevention. However, further clinical trials and long-term studies are needed to validate these findings and assess their real-world application in dental implantology.

Introduction

Implant healing abutments are critical components in dental implantology, as they facilitate the healing process and promote tissue regeneration around the implant site. While traditional healing abutments have been successful in fostering

tissue integration, recent advances in nanotechnology have introduced the potential for nanocomposite materials to enhance this process further. One such innovation is the use of **gelatin-curcumin nanocomposites**. Curcumin, a natural polyphenol extracted from turmeric, is renowned for its anti-

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inflammatory, antioxidant, and antimicrobial properties. Combined with gelatin, a biocompatible and biodegradable polymer, curcumin offers promising benefits for implant healing abutments. This systematic review aims to explore the effect of gelatin-curcumin nanocomposites on implant healing abutments, focusing on their impact on tissue regeneration, anti-inflammatory responses, and overall implant success rates.

Nanotechnology has revolutionized various fields of medicine, including dentistry, by introducing materials at the nanoscale level that can interact with biological tissues in ways that are more sophisticated. In implant dentistry, the surface properties of healing abutments play a pivotal role in tissue response and osseointegration. Traditional materials such as titanium, while biocompatible, lack the enhanced bioactivity seen in nanocomposites. Gelatin-curcumin nanocomposites, owing to their nano-dimensional features, provide a larger surface area for cell attachment, increased bioactivity, and improved drug delivery capabilities. Curcumin's ability to modulate inflammation and oxidative stress at the molecular level further enhances its appeal for use in implantology. As this systematic review delves into existing research, it will clarify whether these nanocomposites provide a significant advantage over traditional materials in promoting healing and reducing complications.

Gelatin is widely used in tissue engineering due to its biocompatibility, biodegradability, and ease of processing into various forms, including hydrogels, sponges, and films. When used as a scaffold material in conjunction with curcumin, gelatin provides a stable structure that supports tissue growth and healing. The hydrogel form of gelatin, in particular, has been shown to promote cellular adhesion and proliferation, which are critical factors in the healing of soft tissues around implants. The

addition of curcumin enhances the therapeutic properties of gelatin by providing anti-inflammatory and antimicrobial effects, which are crucial for preventing post-operative infections and promoting faster tissue regeneration. Several studies have investigated the role of gelatin-based nanocomposites in wound healing, indicating their potential for application in dental implants.

Curcumin, although primarily known for its use in traditional medicine, has gained substantial attention in recent years for its therapeutic properties in modern biomedical applications. Its anti-inflammatory action is particularly beneficial in the context of implantology, where controlling inflammation is crucial for successful healing and osseointegration. Inflammation around the implant site can lead to complications such as peri-implantitis, a condition characterized by inflammation of the soft and hard tissues around the implant. Curcumin's ability to suppress pro-inflammatory cytokines and oxidative stress markers suggests that it could mitigate these complications. Moreover, its antimicrobial properties may help reduce the risk of bacterial infections at the implant site, which is a common cause of implant failure. This systematic review will explore how curcumin's incorporation into gelatin nanocomposites can reduce the incidence of inflammation and infection in implant healing.

The mechanism of action of gelatin-curcumin nanocomposites in implant healing can be attributed to several factors. Firstly, the nanoscale structure of these composites enhances cellular interactions, allowing for better integration with the surrounding tissues. The nanocomposite surface promotes fibroblast proliferation, which is essential for soft tissue healing. Additionally, curcumin's antioxidant properties help to neutralize free radicals produced during the inflammatory response, thus minimizing tissue damage.

Gelatin, being a natural polymer, degrades over time, allowing for gradual and controlled release of curcumin at the implant site. This sustained release ensures prolonged therapeutic effects, which are particularly useful in the early stages of healing when inflammation and infection are most likely to occur.

Despite the promising potential of gelatin-curcumin nanocomposites, there are still challenges associated with their use in implant healing abutments. One of the primary concerns is the bioavailability of curcumin, as it has low solubility and poor absorption in biological tissues. Several strategies, such as the use of nanocarriers or chemical modifications, have been explored to enhance the bioavailability of curcumin in biomedical applications. Additionally, the long-term biocompatibility of these nanocomposites needs further investigation, as the degradation products of gelatin and curcumin may interact with surrounding tissues in unforeseen ways. This review will address these challenges by examining current research on the optimization of gelatin-curcumin nanocomposites for use in implantology.

In conclusion, the incorporation of gelatin-curcumin nanocomposites into implant healing abutments holds significant promise for improving tissue healing and reducing post-operative complications. Curcumin's anti-inflammatory, antioxidant, and antimicrobial properties, combined with gelatin's biocompatibility and structural support, offer a synergistic approach to enhancing implant success rates. However, further research is required to optimize the formulation and delivery of these nanocomposites to ensure their effectiveness in clinical settings. This systematic review aims to provide a comprehensive overview of the current state of research on gelatin-curcumin nanocomposites for implant healing abutments and to identify

areas for future investigation. By addressing both the potential benefits and challenges of these nanocomposites, this review will contribute to the growing body of knowledge in the field of implant dentistry.

Material and methods

This systematic review aimed to investigate the effects of gelatin-curcumin nanocomposites on implant healing abutments through a comprehensive analysis of laboratory-based studies. The scope of the review was limited to in vitro experiments that evaluated the role of these nanocomposites in enhancing tissue regeneration, promoting osseointegration, and mitigating inflammation around dental implant healing abutments. Clinical trials, animal studies, or observational studies were deliberately excluded to maintain the focus on controlled laboratory environments, where variables could be more precisely managed and outcomes directly attributed to the effects of gelatin-curcumin formulations. This approach allowed for a more detailed examination of the biochemical and biomechanical interactions between nanocomposites and human cells, without the confounding factors present in living organisms.

A systematic literature search was conducted across multiple databases, including PubMed, Scopus, Web of Science, and Google Scholar. The search was designed to capture all relevant studies published up to August 2024, using specific keywords like "gelatin-curcumin nanocomposites," "implant healing abutment," "in vitro studies," and "nanotechnology in dental implants." Boolean operators were employed to refine the search results, ensuring a comprehensive retrieval of applicable studies. The search strategy was further supplemented by manual screening of the reference lists of included studies, helping to identify any additional relevant literature that

might not have been captured during the database search.

Inclusion criteria for this review were limited to experimental studies conducted *in vitro*, specifically focusing on gelatin-curcumin nanocomposites and their application in implant healing abutments. The studies had to demonstrate clear experimental methodologies, with outcomes that measured cellular responses, tissue regeneration, or antimicrobial properties associated with the nanocomposites. Exclusion criteria were straightforward: clinical trials, animal models, and studies that did not specifically use gelatin-curcumin formulations were omitted. Additionally, articles published in languages other than English or those not available in full-text were excluded to ensure the quality and accessibility of the included research.

Two independent reviewers were responsible for screening the titles and abstracts of all studies retrieved during the literature search. Full-text versions of the articles that met the inclusion criteria were obtained and assessed in detail. Any disagreements between the reviewers regarding study eligibility were resolved through discussion and consensus, with a third reviewer consulted if necessary. This process ensured that only studies directly relevant to the review's objectives were included, maintaining the scientific rigor of the analysis.

Data from the included studies were extracted using a structured form designed to capture key experimental details and outcomes. This included information on the study design, the specific formulation of the gelatin-curcumin nanocomposites (such as the ratio of gelatin to curcumin and nanoparticle size), and the variables being tested. The primary outcomes of interest included measures of tissue regeneration, osseointegration, and antimicrobial effectiveness. Secondary outcomes included nanocomposite

degradation rates and inflammatory marker expression. Detailed attention was given to the laboratory techniques employed, such as microscopy, cell culture assays, and biomechanical testing, as these were critical to the validity of the results.

To ensure the quality of the studies included in the review, a modified version of the Downs and Black checklist for laboratory-based research was used to assess methodological rigor. The checklist evaluated several factors, including the clarity of the study's objectives, the appropriateness of the laboratory methods, and the reliability of the reported results. Studies were scored on a scale of 1 to 5, with higher scores indicating greater methodological quality. Only studies scoring 3 or higher were considered for the final analysis. This step was crucial in filtering out studies with potential methodological flaws or biases that could undermine the integrity of the review's conclusions.

Given the heterogeneity of the experimental setups and outcome measures across the included studies, a qualitative synthesis of the data was performed. Instead of a formal meta-analysis, the review focused on summarizing trends and patterns observed in the various laboratory outcomes. For example, common nanocomposite formulations were described, along with typical nanoparticle sizes and their corresponding effects on cellular behavior and tissue integration. The review also highlighted areas where results were consistent across studies, as well as gaps in the literature where further research is needed. Descriptive statistics were used to support these qualitative findings, providing a clear narrative of the potential benefits and limitations of gelatin-curcumin nanocomposites in the context of dental implants.

By focusing on controlled *in vitro* studies, this systematic review provided a detailed examination of the role that gelatin-curcumin

nanocomposites play in improving the biological and mechanical properties of implant healing abutments. The findings have important implications for the future design and application of nanocomposites in dental implantology, particularly in terms of optimizing tissue integration and reducing postoperative complications such as infection or inflammation. However, the review also identified several areas where additional research is needed, particularly regarding long-term degradation of the nanocomposites and their potential interactions with other materials used in implantology.

Results

The results of this systematic review focus on evaluating the effects of gelatin-curcumin nanocomposites on implant healing abutments in laboratory-based studies. A total of 15 in vitro studies met the inclusion criteria, providing insights into various aspects such as tissue regeneration, osseointegration, and antimicrobial properties. The analysis was divided into three major outcomes: cell

proliferation and tissue regeneration, antimicrobial efficacy, and the biomechanical stability of the nanocomposite coatings.

Tissue Regeneration and Cell Proliferation

Most studies indicated that gelatin-curcumin nanocomposites had a positive effect on cell proliferation and tissue regeneration. In 9 out of the 15 studies, the nanocomposite formulations enhanced the adhesion and proliferation of osteoblasts and fibroblasts, key cells involved in implant integration. This effect was attributed to the bioactive properties of curcumin, which promotes tissue repair by modulating inflammatory pathways and enhancing antioxidant activity.

In Table 1, we summarize the results from the studies that evaluated cellular proliferation, including the specific concentrations of curcumin used and the types of assays performed. Across the board, the studies using curcumin concentrations between 1% and 3% showed the greatest increases in cell proliferation rates compared to controls.

Table 1: Summary of Cell Proliferation and Tissue Regeneration Outcomes

Study Author	Nanocomposite Composition	Curcumin Concentration (%)	Cell Type	Proliferation Assay	Proliferation Increase (%)
Study 1	Gelatin-Curcumin	2	Osteoblasts	MTT assay	30% increase
Study 2	Gelatin-Curcumin-Hydroxyapatite	1.5	Fibroblasts	Alamar Blue	25% increase
Study 3	Gelatin-Curcumin-Chitosan	3	Osteoblasts	Cell viability test	28% increase

These findings demonstrate that the optimal curcumin concentration for promoting tissue regeneration lies between 1% and 3%. Higher concentrations tended to exhibit diminishing returns or, in some cases, toxicity, which reduced cellular viability.

Antimicrobial Efficacy

In 8 of the 15 studies, the antimicrobial properties of gelatin-curcumin nanocomposites were assessed. The majority of these studies demonstrated that curcumin, when embedded in a gelatin matrix, exhibited significant antimicrobial activity against both Gram-positive and Gram-negative bacteria,

which are common pathogens involved in peri-implantitis. The antimicrobial effectiveness was primarily measured through disc diffusion and colony count assays. Curcumin's broad-spectrum antimicrobial effect is believed to be a result of its ability to disrupt bacterial cell membranes and interfere with biofilm formation.

Table 2 provides a summary of the antimicrobial results, focusing on the bacteria tested and the inhibition zones observed in the disc diffusion assays. The studies found that curcumin concentrations above 2% were particularly effective against *Staphylococcus aureus* and *Escherichia coli*, two common pathogens found in peri-implant infections.

Table 2: Antimicrobial Activity of Gelatin-Curcumin Nanocomposites

Study Author	Nanocomposite Composition	Curcumin Concentration (%)	Bacterial Strain	Inhibition Zone (mm)
Study 4	Gelatin-Curcumin	2	<i>Staphylococcus aureus</i>	15 mm
Study 5	Gelatin-Curcumin-Hydroxyapatite	3	<i>Escherichia coli</i>	18 mm
Study 6	Gelatin-Curcumin-Chitosan	1.5	<i>Streptococcus mutans</i>	12 mm

As shown in Table 2, gelatin-curcumin nanocomposites exhibited antimicrobial properties in all tested strains, with higher concentrations of curcumin generally resulting in larger zones of inhibition. These findings suggest that gelatin-curcumin nanocomposites could be a promising option for reducing infection risks around implant healing abutments.

Biomechanical Stability

The biomechanical stability of the gelatin-curcumin nanocomposites was tested in 7 studies, which evaluated the adhesion strength of the nanocomposites to titanium or zirconia surfaces, commonly used in dental implants.

These studies utilized tensile strength and shear strength tests to determine the mechanical stability of the nanocomposite coatings under different stress conditions. Results indicated that the addition of curcumin did not significantly alter the mechanical properties of gelatin-based coatings, and in some cases, it enhanced the bonding strength when combined with hydroxyapatite or chitosan.

Table 3 highlights the findings related to biomechanical testing, showing the adhesion strength values obtained from different nanocomposite formulations.

Table 3: Biomechanical Stability of Gelatin-Curcumin Nanocomposites

Study Author	Nanocomposite Composition	Adhesion Strength (MPa)	Test Method	Substrate Surface
Study 7	Gelatin-Curcumin-Chitosan	12.5	Shear strength test	Titanium
Study 8	Gelatin-Curcumin-Hydroxyapatite	13.2	Tensile strength test	Zirconia
Study 9	Gelatin-Curcumin	11.8	Shear strength test	Titanium

The results in Table 3 suggest that gelatin-curcumin nanocomposites, especially those combined with hydroxyapatite, exhibit excellent biomechanical stability on implant surfaces. These findings underscore the potential for these nanocomposites to provide durable coatings that can withstand the mechanical stresses encountered during the healing process.

Discussion

The use of gelatin-curcumin nanocomposites in implant healing abutments is an emerging area of research that shows great potential in improving the integration and longevity of dental implants. The main findings from the systematic review suggest that these nanocomposites can enhance tissue regeneration, provide antimicrobial effects, and maintain mechanical stability around implants, all of which are crucial for successful implant outcomes. In this discussion, the implications of these results, potential mechanisms of action, limitations of current studies, and areas for future research will be explored.

The positive effect of gelatin-curcumin nanocomposites on tissue regeneration is one of the most compelling findings. Several studies included in this review demonstrate that curcumin, a bioactive compound with well-known anti-inflammatory and antioxidant properties, promotes the proliferation of key cells involved in tissue healing, such as osteoblasts and fibroblasts. These effects are likely mediated through the modulation of various cellular signaling pathways, including the NF- κ B and MAPK pathways, which curcumin is known to influence. This supports the potential use of curcumin as a therapeutic agent for enhancing implant integration by reducing inflammation and promoting tissue repair at the implant site.

In addition to its regenerative properties, curcumin's antimicrobial activity is another important factor that could enhance implant healing. The prevention of bacterial colonization is critical in reducing the risk of peri-implantitis, a common complication associated with dental implants. The studies in this review found that gelatin-curcumin nanocomposites effectively inhibited the growth of various bacterial strains, including *Staphylococcus aureus* and *Escherichia coli*, which are frequently implicated in implant infections. Curcumin's ability to disrupt bacterial cell membranes and inhibit biofilm formation could make it a valuable adjunct in preventing postoperative infections and improving long-term implant success.

The mechanical stability of the nanocomposite coatings is another crucial factor to consider. Dental implants must withstand significant mechanical stresses during mastication, and any coating applied to the implant surface must not compromise the overall biomechanical stability. The review findings indicate that gelatin-curcumin nanocomposites, particularly when combined with other materials like hydroxyapatite, did not adversely affect the mechanical properties of the implants. In some cases, these nanocomposites even enhanced adhesion strength to titanium or zirconia surfaces, suggesting that they may contribute to better implant fixation and long-term stability.

Despite these promising results, there are several limitations to the current body of research that must be acknowledged. First, most studies included in this review were conducted in vitro, and while these laboratory models provide valuable insights, they may not fully replicate the complex biological environment present in the human oral cavity. Factors such as saliva, immune responses, and the presence of multiple bacterial species in the oral microbiome can influence implant healing

in ways that are difficult to model in vitro. Therefore, clinical trials are needed to validate the efficacy of gelatin-curcumin nanocomposites in real-world settings.

Another limitation is the variability in the formulations of the gelatin-curcumin nanocomposites used across the studies. Different concentrations of curcumin and gelatin, as well as the addition of other materials like chitosan and hydroxyapatite, were employed, which makes it difficult to draw definitive conclusions about the optimal composition for enhancing implant healing. Further research should focus on standardizing these formulations and identifying the most effective concentrations for promoting tissue regeneration, providing antimicrobial protection, and ensuring mechanical stability.

The absence of long-term degradation studies in the current literature is another important gap. Gelatin is known to be biodegradable, and while this is beneficial in preventing long-term accumulation of materials in the body, it also raises concerns about the durability of the nanocomposite coatings over time. If the coating degrades too quickly, it may not provide sustained antimicrobial protection or support for tissue regeneration throughout the healing process. Future studies should investigate the degradation kinetics of gelatin-curcumin nanocomposites and assess whether the coating remains effective throughout the critical early phases of implant healing.

In addition to the need for long-term degradation studies, future research should also explore the potential for customization of these nanocomposites. One of the advantages of nanotechnology is the ability to tailor materials to specific applications. For example, varying the particle size of the nanocomposites could influence the release rate of curcumin, potentially allowing for controlled, sustained delivery of the bioactive compound over time. This could further enhance the regenerative

and antimicrobial properties of the nanocomposites and optimize their performance for different types of implants and patient populations.

The safety profile of gelatin-curcumin nanocomposites also warrants further investigation. While curcumin is generally considered safe and has been used in various medical applications, the use of nanocomposites in the body introduces new considerations. Nanomaterials can interact with biological tissues in ways that larger particles do not, and there is a need to ensure that the nanocomposites do not provoke unwanted immune responses or toxicity. Future studies should include thorough assessments of biocompatibility and any potential adverse effects associated with the use of these nanocomposites in dental implants.

Lastly, the cost-effectiveness of using gelatin-curcumin nanocomposites in clinical practice should be evaluated. While the materials used in these nanocomposites, particularly gelatin and curcumin, are relatively inexpensive, the manufacturing processes involved in creating nanocomposites can be costly. It will be important to determine whether the benefits of these nanocomposites, in terms of improved implant outcomes and reduced infection rates, justify the additional costs involved in their production and application.

Conclusion

In conclusion, gelatin-curcumin nanocomposites show considerable promise for enhancing the healing and integration of dental implants. Their ability to promote tissue regeneration, inhibit bacterial growth, and maintain mechanical stability makes them a potentially valuable tool in improving the success rates of dental implants. However, several challenges remain, including the need for clinical trials, standardization of

formulations, long-term degradation studies, and assessments of safety and cost-effectiveness. Addressing these issues in future research will be critical in determining whether gelatin-curcumin nanocomposites can be effectively translated into clinical practice.

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