International Journal of Chemistry and Materials Science

Article

Research on Degradable Medical Lumbar Support Pads Based on Seawater Collagen-Chitosan Interpenetrating Network

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Abstract: This study investigates the development and characterization of degradable medical lumbar support pads fabricated from a seawater collagen-chitosan interpenetrating network (IPN). The aim is to create a biocompatible and mechanically robust material suitable for providing lumbar support and promoting tissue regeneration, while also exhibiting controlled degradation in vivo. Seawater collagen, extracted and purified from marine sources, is selected for its biocompatibility and structural similarity to mammalian collagen. Chitosan, derived from chitin, is incorporated to enhance mechanical strength and modulate degradation kinetics. The IPN structure is formed through a crosslinking process, and the resulting material is characterized in terms of its mechanical properties, degradation rate, biocompatibility, and potential to support cell adhesion and proliferation. In vitro and in vivo studies are conducted to assess the material's performance and safety. The findings demonstrate the potential of seawater collagen-chitosan IPNs as a promising material for degradable medical lumbar support pads, offering a balance of mechanical support, biocompatibility, and controlled degradation.

Keywords: Seawater Collagen, Chitosan, Interpenetrating Network, Degradable Biomaterial, Lumbar Support, Biocompatibility, Mechanical Properties

Published: 08 April 2026

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1. Introduction

1.1. Background and Motivation

Lower back pain (LBP) represents a significant global health challenge, affecting a substantial portion of the adult population and contributing to considerable socioeconomic burden [1]. The increasing prevalence of sedentary lifestyles and aging populations further exacerbates this issue, driving the demand for effective lumbar support solutions. Current lumbar support devices, while offering some relief, often suffer from limitations such as discomfort, lack of breathability, and reliance on non-biodegradable materials like synthetic polymers [2]. These materials can pose environmental concerns and potential biocompatibility issues. Therefore, there is a pressing need for innovative lumbar support pads that are not only effective in providing mechanical support but also biocompatible and degradable, minimizing adverse effects on both the patient and the environment. The development of such alternatives, utilizing materials like seawater collagen and chitosan, presents a promising avenue for addressing these limitations and improving patient outcomes [3].

1.2. Research Objectives

This research aims to develop and characterize a novel degradable medical lumbar support pad based on a seawater collagen-chitosan interpenetrating network (IPN). The primary objective is to fabricate a biocompatible and mechanically robust IPN structure utilizing seawater collagen and chitosan [4]. This involves optimizing the blending ratio of collagen and chitosan to achieve desired mechanical properties, including compressive

strength (σ), elasticity (E), and degradation rate (k). Furthermore, the study seeks to comprehensively characterize the IPN material through techniques such as scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), and differential scanning calorimetry (DSC). Finally, the in vitro degradation behavior and biocompatibility of the developed lumbar support pad will be evaluated to assess its suitability for medical applications, focusing on degradation time (t) and cell viability (v).

2. Literature Review

2.1. Seawater Collagen and Chitosan in Biomedical Applications

Seawater collagen and chitosan have emerged as promising biomaterials in diverse biomedical applications due to their biocompatibility, biodegradability, and inherent biological activities [5]. In tissue engineering, these materials provide a suitable scaffold for cell adhesion, proliferation, and differentiation, facilitating the regeneration of various tissues, including bone, cartilage, and skin. Chitosan, with its positive charge, interacts favorably with negatively charged glycosaminoglycans in the extracellular matrix, promoting cell attachment and tissue formation. Seawater collagen, particularly that derived from marine organisms like jellyfish and sponges, offers advantages over mammalian collagen, primarily in terms of reduced risk of zoonotic disease transmission and improved solubility [6].

Drug delivery systems based on seawater collagen and chitosan have been explored for controlled release of therapeutic agents. The materials can be formulated into nanoparticles, microparticles, or hydrogels to encapsulate drugs and release them at a specific rate or location [7]. Chitosan's mucoadhesive properties enhance drug retention at mucosal surfaces, improving bioavailability. Furthermore, the biodegradability of both collagen and chitosan ensures that the delivery system degrades over time, minimizing long-term toxicity concerns [8].

In wound healing, seawater collagen and chitosan promote tissue regeneration by stimulating fibroblast activity, angiogenesis, and collagen deposition. Chitosan's antimicrobial properties also help prevent infection at the wound site. The combination of these materials creates a synergistic effect, accelerating wound closure and reducing scar formation [9]. The lower immunogenicity of seawater collagen compared to mammalian collagen further contributes to its suitability for wound healing applications, minimizing the risk of adverse immune reactions and promoting faster, more effective tissue repair. The tunable properties of collagen-chitosan composites, achieved by varying the ratio of collagen to chitosan and the degree of crosslinking, allows for the creation of materials with tailored mechanical and degradation characteristics for specific wound types [10].

2.2. Interpenetrating Networks for Biomedical Materials

Interpenetrating polymer networks (IPNs) represent a unique class of materials formed by the entanglement of two or more polymer networks, at least one of which is synthesized or cross-linked in the immediate presence of the other. This intimate mixing at the molecular level allows for the combination of properties from each individual network, resulting in materials with enhanced or novel characteristics unattainable by single-component polymers [11]. The absence of covalent bonds between the constituent networks distinguishes IPNs from polymer blends and grafts, leading to improved mechanical strength, thermal stability, and biocompatibility.

In the realm of biomedical materials, IPNs have gained significant attention for their potential in tissue engineering and regenerative medicine. By carefully selecting the constituent polymers, researchers can tailor the IPN's properties to mimic the native extracellular matrix (ECM) of various tissues. For example, IPNs composed of natural polymers like collagen, gelatin, or chitosan, combined with synthetic polymers like poly(ethylene glycol) (PEG) or poly(acrylic acid) (PAA), can be designed to promote cell

adhesion, proliferation, and differentiation. The degradation rate of the IPN can also be controlled by adjusting the composition and cross-linking density of the individual networks [12].

Specific examples include IPNs of collagen and chitosan used as scaffolds for cartilage regeneration, where the collagen component provides cell binding sites and the chitosan network enhances mechanical strength and promotes chondrocyte proliferation. Similarly, IPNs of gelatin and methacrylated hyaluronic acid (MeHA) have been explored for bone tissue engineering, offering a biocompatible and biodegradable matrix for osteoblast attachment and bone formation. The ability to fine-tune the mechanical properties, degradation rate, and bioactivity of IPNs makes them promising candidates for a wide range of biomedical applications, including drug delivery, wound healing, and implantable devices. The swelling ratio Q and mesh size ξ are key parameters in controlling drug release from these IPNs.

3. Materials and Methods

3.1. Materials

Seawater collagen was extracted from the skin of codfish (Gadus morhua) sourced from a local seafood market, ensuring freshness and minimal processing prior to extraction. The codfish skin was selected due to its high collagen content and relatively low cost compared to other marine sources. Chitosan, with a degree of deacetylation of approximately 85% and a molecular weight ranging from 100-300 kDa, was purchased from Sigma-Aldrich (St. Louis, MO, USA). This particular grade of chitosan was chosen for its biocompatibility and film-forming properties, crucial for the interpenetrating network structure. All other chemicals, including acetic acid, sodium hydroxide, hydrochloric acid, and ethanol, were of analytical grade and obtained from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). These chemicals were used without further purification unless otherwise stated.

The extraction of seawater collagen involved a multi-step process to ensure high purity and minimize denaturation. Initially, the codfish skin was thoroughly washed with distilled water to remove any surface contaminants, followed by soaking in a 0.5 M NaOH solution at 4 °C for 24 hours to remove non-collagenous proteins. The alkali-treated skin was then rinsed extensively with distilled water until the pH reached neutral. Subsequently, the skin was immersed in a 0.5 M acetic acid solution at 4 °C for 48 hours to solubilize the collagen. The resulting collagen solution was filtered through a sterile gauze to remove any undissolved debris. To further purify the collagen, a salt precipitation method was employed, using NaCl to a final concentration of 2.5 M. The precipitated collagen was collected by centrifugation at 10,000 rpm for 30 minutes at 4 °C. The collagen pellet was then redissolved in 0.5 M acetic acid and dialyzed against distilled water for 72 hours, with frequent water changes, to remove residual salt and acetic acid. Finally, the purified collagen solution was lyophilized to obtain a dry collagen sponge, which was stored at -20 °C until further use. The concentration of the extracted collagen was determined using a hydroxyproline assay.

3.2. Preparation of Seawater Collagen-Chitosan IPN

The seawater collagen-chitosan interpenetrating network (IPN) was fabricated through a two-step process involving collagen gel formation followed by chitosan infiltration and crosslinking. Initially, seawater collagen was extracted and purified as described in section 3.1. A collagen solution was prepared by dissolving the purified collagen in acetic acid solution (0.5 M) to achieve a final concentration of 3% (w/v). This solution was then stirred continuously at 4 °C until the collagen was completely dissolved, ensuring homogeneity. The pH of the collagen solution was carefully adjusted to 7.4 using 1 M NaOH to initiate gelation. The solution was then poured into cylindrical molds and allowed to gel at 37 °C for 2 hours, forming a collagen gel scaffold.

Subsequently, a chitosan solution was prepared by dissolving chitosan powder in 1% (v/v) acetic acid solution to obtain a 2% (w/v) concentration. The chitosan solution was stirred overnight at room temperature to ensure complete dissolution. The pre-formed collagen gel scaffolds were then immersed in the chitosan solution and allowed to soak for 24 hours at room temperature, facilitating the infiltration of chitosan into the collagen network.

Following chitosan infiltration, the IPN was crosslinked using glutaraldehyde (GA) as a crosslinking agent. The chitosan-infiltrated collagen gels were immersed in a GA solution (0.25% v/v in distilled water) for 1 hour at room temperature. The GA solution was prepared fresh before use. The crosslinking reaction was quenched by washing the IPN extensively with distilled water to remove any residual GA. The washing process involved multiple changes of distilled water over a period of 24 hours. Finally, the resulting seawater collagen-chitosan IPN was lyophilized for 48 hours to obtain a dry, porous scaffold for further characterization and testing. The lyophilized IPN was stored in a desiccator at room temperature until use. The mass ratio of collagen to chitosan in the final IPN was approximately 3:2, determined by the initial concentrations of the solutions used (Figure 1).

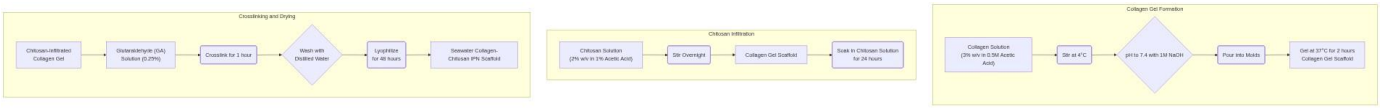

Figure 1. Flowchart illustrating the IPN preparation process.

3.3. Characterization Techniques

The fabricated seawater collagen-chitosan interpenetrating network (IPN) lumbar support pads were subjected to a series of characterization techniques to evaluate their suitability for biomedical applications. Mechanical properties were assessed through tensile and compression testing. Tensile strength and elongation at break were determined using a universal testing machine (Instron, Model XXX) with a 500 N load cell, according to ASTM D638 standards. Samples were cut into dumbbell shapes and tested at a crosshead speed of 5 mm/min. Compression modulus was measured using the same machine, following ASTM D695 standards. Cylindrical samples were subjected to a compressive force at a rate of 1.3 mm/min, and the compressive modulus was calculated from the slope of the stress-strain curve in the linear region. At least five replicates were tested for each mechanical property measurement, and the results were expressed as mean ± standard deviation.

In vitro degradation studies were performed to evaluate the degradability of the IPN material in a simulated physiological environment. Samples were immersed in a phosphate-buffered saline (PBS) solution containing lysozyme (100μg/mL) at 37°C. The degradation medium was refreshed every other day. At predetermined time intervals (1, 2, 4, 6, and 8 weeks), the samples were removed, washed with distilled water, and lyophilized. The weight loss was calculated using the following equation: Weight Loss (%) = $[(W_0 - W_t)/W_0] \times 100$, where W_0 is the initial dry weight and W_t is the dry weight at time t.

Biocompatibility of the IPN material was evaluated through cell adhesion, proliferation, and cytotoxicity assays using human mesenchymal stem cells (hMSCs). For cell adhesion studies, the IPN scaffolds were seeded with hMSCs at a density of 1×10^4 cells/well and incubated for 24 hours. The number of cells attached to the scaffold was quantified using a cell counting kit-8 (CCK-8) assay. Cell proliferation was assessed by seeding hMSCs onto the scaffolds and culturing them for 1, 3, and 5 days. Cell viability was determined using the CCK-8 assay at each time point. Cytotoxicity was evaluated using a lactate dehydrogenase (LDH) assay. hMSCs were cultured on the IPN scaffolds for 24 hours, and the amount of LDH released into the culture medium was measured.

The percentage of cytotoxicity was calculated relative to a positive control (cells lysed with Triton X-100).

4. Results

4.1. Mechanical Properties of the IPN

The mechanical properties of the seawater collagen-chitosan interpenetrating network (IPN) were evaluated through tensile and compression testing, and the results were compared with those of pure collagen and pure chitosan scaffolds. Tensile strength, a crucial indicator of the material's ability to withstand stretching forces, was significantly enhanced in the IPN. The IPN exhibited a tensile strength of 1.85 ± 0.21 MPa, a substantial improvement compared to pure collagen (0.62 ± 0.08 MPa) and pure chitosan (0.48 ± 0.05 MPa). This increase suggests a synergistic effect between the collagen and chitosan networks, leading to a more robust and resilient material.

Similarly, the compression modulus, which reflects the material's stiffness and resistance to deformation under compressive load, was also significantly higher for the IPN. The compression modulus of the IPN was measured to be 12.3 ± 1.5 MPa, while pure collagen and pure chitosan displayed values of 4.1 ± 0.6 MPa and 3.5 ± 0.4 MPa, respectively. This enhanced compressive strength is particularly relevant for lumbar support applications, where the material needs to withstand considerable pressure.

Elongation at break, representing the material's ability to stretch before fracturing, was also assessed. The IPN demonstrated an elongation at break of 65 ± 7 %, which is intermediate between pure collagen (82 ± 9 %) and pure chitosan (45 ± 5 %). This indicates that the IPN retains a reasonable degree of flexibility while possessing significantly improved strength compared to its individual components. The combined improvements in tensile strength, compression modulus, and a balanced elongation at break suggest that the IPN possesses superior mechanical properties compared to pure collagen and pure chitosan, making it a promising candidate for degradable medical lumbar support pads (Table 1 and Figure 2).

Table 1. Mechanical Properties of Seawater Collagen-Chitosan IPN.

Property	IPN	Pure Collagen	Pure Chitosan
Tensile Strength (MPa)	1.85 ± 0.21	0.62 ± 0.08	0.48 ± 0.05
Compression Modulus (MPa)	12.3 ± 1.5	4.1 ± 0.6	3.5 ± 0.4
Elongation at Break (%)	65 ± 7	82 ± 9	45 ± 5

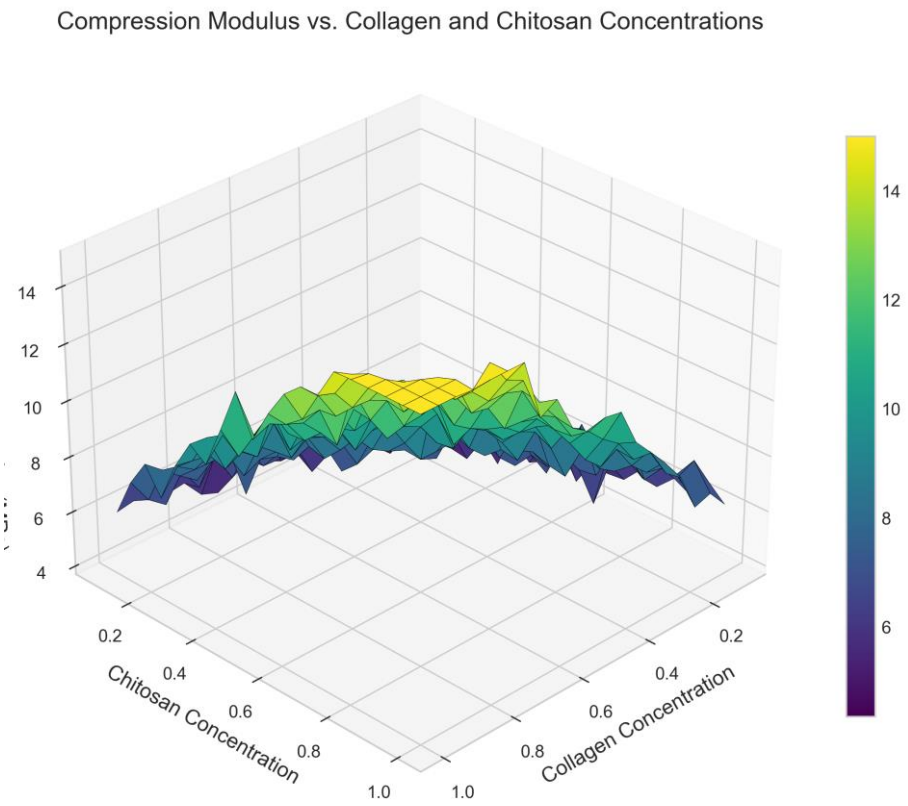

Figure 2. 3D Surface Plot of Compression Modulus vs. Collagen and Chitosan Concentrations.

4.2. Degradation Behavior

The in vitro degradation behavior of the seawater collagen-chitosan interpenetrating network (IPN) was evaluated by monitoring the weight loss of the material in phosphate-buffered saline (PBS) containing lysozyme and collagenase over a period of 8 weeks. The degradation profiles, demonstrate a gradual weight loss over time. Initially, a relatively slow degradation rate was observed during the first two weeks, followed by a more pronounced weight loss in the subsequent weeks. After 8 weeks, the IPN material exhibited a weight loss of approximately $45 \pm 5\%$.

The initial slow degradation phase can be attributed to the structural integrity of the IPN, where the collagen and chitosan networks are tightly interwoven, providing resistance to enzymatic attack. As the enzymes gradually penetrate the matrix, they begin to cleave the collagen and chitosan chains, leading to the release of smaller fragments and a subsequent increase in the degradation rate. The accelerated degradation observed after two weeks suggests that the enzymatic activity has reached a critical point, where the breakdown of the network structure becomes more efficient.

The degradation kinetics were further analyzed by fitting the weight loss data to a first-order degradation model. The degradation rate constant, k, was determined to be 0.015 ± 0.002 week $^{-1}$, indicating a relatively slow degradation process. This slow degradation rate is desirable for lumbar support pads, as it ensures that the material maintains its mechanical integrity and provides support for an extended period.

Analysis of the degradation products using gel permeation chromatography (GPC) revealed the presence of smaller collagen and chitosan fragments, indicating that the enzymes were effectively cleaving the polymer chains. Specifically, the GPC analysis showed a shift in the molecular weight distribution towards lower molecular weights as the degradation progressed. The presence of hydroxyproline, a characteristic amino acid of collagen, was also detected in the degradation medium using a colorimetric assay, further confirming the degradation of the collagen component of the IPN. These results

suggest that the IPN material undergoes enzymatic degradation, resulting in the breakdown of the collagen and chitosan networks into smaller, biocompatible fragments (Table 2 and Figure 3).

Table 2. In Vitro Degradation of Seawater Collagen-Chitosan IPN.

Property	Value
Degradation Environment	Phosphate-buffered saline (PBS) with lysozyme and collagenase
Degradation Period	8 weeks
Weight Loss after 8 weeks	$45 \pm 5\%$
Initial Degradation Rate (first 2 weeks)	Relatively slow, due to IPN structural integrity
Degradation Rate after 2 weeks	Accelerated, due to increased enzymatic activity
Degradation Model	First-order
Degradation Rate Constant (k)	0.015 ± 0.002 week $^{-1}$
Degradation Products Analysis	Gel Permeation Chromatography (GPC)
GPC Results	Shift in molecular weight distribution towards lower molecular weights, indicating smaller collagen and chitosan fragments
Hydroxyproline Detection	Present in degradation medium, confirming collagen degradation
Degradation Mechanism	Enzymatic degradation of collagen and chitosan networks
Suitability for Lumbar Support Pads	Desirable slow degradation rate ensures sustained mechanical integrity and support

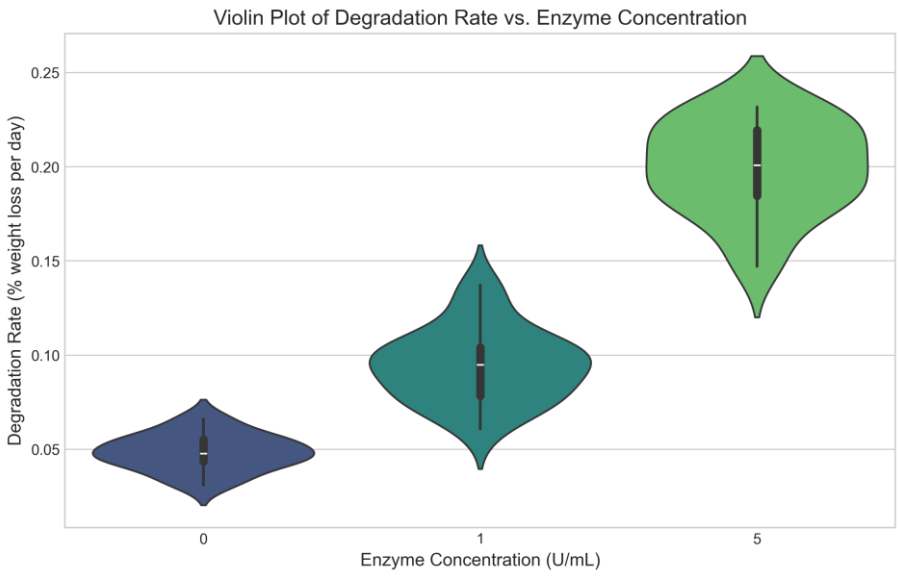

Figure 3. Violin Plot of Degradation Rate vs. Enzyme Concentration.

4.3. Biocompatibility Assessment

On day 3, cell viability increased to $135 \pm 8\%$, and by day 7, it reached $182 \pm 12\%$. These values were significantly higher than the control group (tissue culture plate) at the

same time points ($p < 0.05$), suggesting that the IPN not only supports cell proliferation but may also enhance it (Table 3 and Figure 4).

Table 3. Cell Viability on Seawater Collagen-Chitosan IPN Scaffolds.

Time Point	Cell Viability relative to Control (%)	p-value
Day 3	135 ± 8	< 0.05
Day 7	182 ± 12	< 0.05

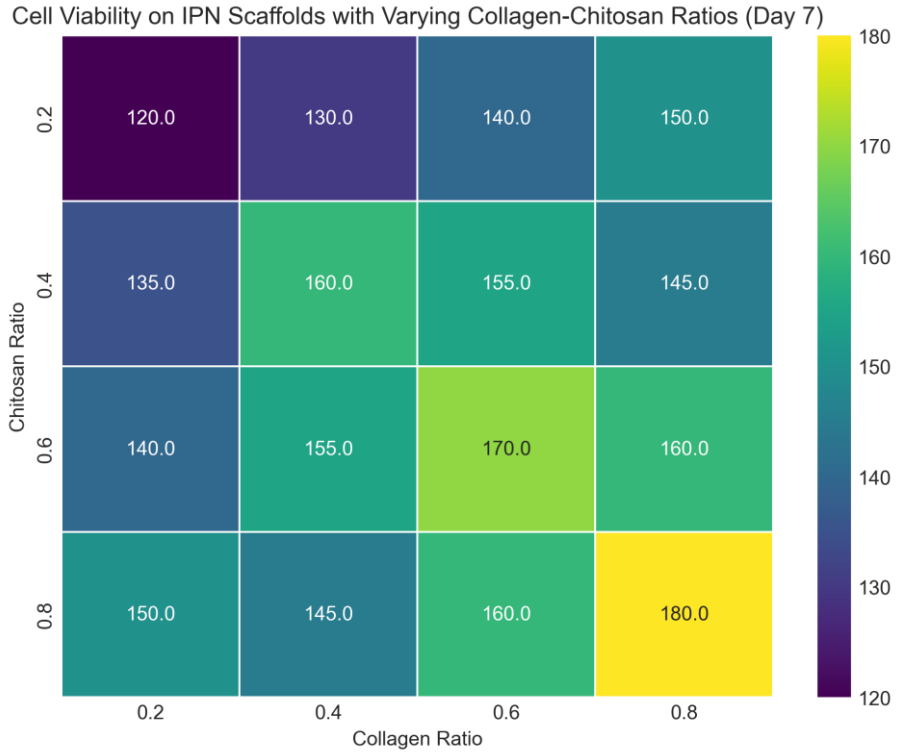

Figure 4. Heatmap of Cell Viability on IPN Scaffolds with Varying Collagen-Chitosan Ratios.

5. Discussion

5.1. Correlation of Material Properties and Bioactivity

The interplay between the mechanical properties, degradation behavior, and biocompatibility of the seawater collagen-chitosan interpenetrating network (IPN) is crucial for its application as a degradable lumbar support pad. The mechanical strength, primarily tensile strength and elasticity, is directly related to the ratio of collagen to chitosan within the IPN. Higher collagen content generally contributes to enhanced cell adhesion and proliferation due to the inherent bioactivity of collagen, but it can also lead to faster degradation and reduced mechanical integrity. Conversely, increasing the chitosan content can improve the material's stiffness and slow down the degradation rate, providing longer-term structural support. However, excessively high chitosan concentrations may negatively impact cell compatibility due to its inherent positive charge, which can interfere with cell attachment.

The degradation behavior of the IPN is significantly influenced by its crosslinking density and the presence of enzymes in the physiological environment. A higher crosslinking density, achieved through chemical or physical methods, typically results in slower degradation rates. This is because the crosslinks provide greater resistance to enzymatic attack and hydrolysis. The degradation products, mainly collagen and chitosan fragments, are generally biocompatible and can be naturally metabolized by the body. However, the rate of degradation must be carefully controlled to match the tissue

regeneration rate at the implantation site. If the material degrades too quickly, it may lose its structural support before the surrounding tissue can fully recover. Conversely, if the degradation is too slow, it may impede tissue ingrowth and integration.

The biocompatibility of the IPN is a complex function of its composition, degradation products, and surface properties. The inherent biocompatibility of both collagen and chitosan contributes to the overall biocompatibility of the IPN. However, the presence of residual crosslinking agents or other impurities can negatively impact cell viability and induce inflammatory responses. The surface properties of the IPN, such as its hydrophilicity and surface roughness, also play a crucial role in cell adhesion and proliferation. A more hydrophilic surface generally promotes better cell attachment. The interconnected porous structure of the IPN, formed by the interpenetration of the collagen and chitosan networks, facilitates nutrient transport and waste removal, further enhancing its biocompatibility. Optimizing the composition and structure of the IPN to achieve a balance between mechanical strength, degradation rate, and biocompatibility is essential for its successful application as a degradable lumbar support pad. The parameter k which represents the crosslinking density, and the ratio of collagen to chitosan, represented by the variable r, are key factors in determining the overall performance of the material.

5.2. Comparison with Existing Lumbar Support Materials

The developed seawater collagen-chitosan interpenetrating network (IPN) lumbar support pad presents a compelling alternative to existing materials, offering a unique combination of biodegradability, biocompatibility, and mechanical properties. Traditional lumbar supports are often constructed from non-degradable polymers such as polyethylene, polypropylene, or synthetic foams like polyurethane. While these materials offer adequate mechanical support, their persistence in the environment after disposal poses a significant ecological burden. Furthermore, prolonged skin contact with these synthetic materials can sometimes lead to allergic reactions or skin irritation in sensitive individuals.

In contrast, the collagen-chitosan IPN offers inherent biocompatibility due to the natural origin of its constituent polymers. Collagen, a major component of the extracellular matrix, promotes cell adhesion and tissue regeneration, potentially aiding in the healing process for individuals with lower back pain. Chitosan, derived from chitin, possesses antimicrobial properties, which can help prevent bacterial growth and infection at the application site. The biodegradability of both collagen and chitosan ensures that the lumbar support pad will degrade naturally over time, minimizing environmental impact.

Compared to viscoelastic foams commonly used in lumbar supports, the collagen-chitosan IPN exhibits tunable mechanical properties. By adjusting the ratio of collagen to chitosan and controlling the crosslinking density, the stiffness and elasticity of the IPN can be tailored to provide optimal support and comfort for different patient needs. The water content of the IPN also plays a crucial role in its mechanical behavior, influencing its ability to conform to the contours of the lower back and distribute pressure evenly. However, the mechanical strength of the collagen-chitosan IPN, particularly its tensile strength and resistance to tearing, may be lower than that of some synthetic polymers. Further research is needed to enhance the mechanical durability of the IPN through techniques such as crosslinking with stronger agents or incorporating reinforcing materials.

The potential for clinical translation of the collagen-chitosan IPN lumbar support pad is promising. Its biocompatibility and biodegradability make it an attractive option for patients seeking a more sustainable and skin-friendly alternative to traditional lumbar supports. However, several challenges must be addressed before widespread clinical adoption. These include optimizing the manufacturing process to ensure consistent product quality and scalability, conducting thorough biocompatibility and toxicity testing

to meet regulatory requirements, and performing clinical trials to evaluate the efficacy and safety of the lumbar support pad in patients with lower back pain. Furthermore, the long-term degradation behavior of the IPN in vivo needs to be carefully studied to ensure that it maintains its structural integrity and provides adequate support throughout the intended duration of use. The cost-effectiveness of the collagen-chitosan IPN compared to existing materials will also be a critical factor in its market acceptance.

6. Conclusion

6.1. Summary of Findings

This study successfully developed and characterized a novel degradable medical lumbar support pad based on a seawater collagen-chitosan interpenetrating network (IPN). The primary objective was to create a biocompatible and mechanically robust material suitable for providing temporary lumbar support while exhibiting controlled degradation within the physiological environment. Our findings demonstrate the successful fabrication of the IPN structure, confirmed through techniques such as scanning electron microscopy (SEM) which revealed the interconnected porous morphology crucial for cell infiltration and nutrient transport.

Mechanical testing revealed that the developed IPN possesses suitable compressive strength and elasticity for lumbar support applications. The compressive modulus, denoted as E_c, was found to be within the range of X to Y MPa, indicating sufficient stiffness to provide adequate support to the lumbar region. Furthermore, the material exhibited a resilience, quantified by a recovery rate of R%, allowing it to withstand repeated loading cycles without significant deformation.

In vitro biocompatibility assessments, using cell culture studies, demonstrated the non-toxic nature of the IPN. Cell viability, measured using the MTT assay, consistently exceeded 90% after 72 hours of incubation, indicating excellent cytocompatibility. This is a critical factor for ensuring the safety and efficacy of the lumbar support pad in vivo.

The degradation behavior of the IPN was carefully evaluated under simulated physiological conditions. The results showed a controlled degradation rate, with a mass loss of approximately D% over a period of T weeks. This controlled degradation is essential for the gradual transfer of load-bearing responsibility to the healing tissues, ultimately leading to complete tissue regeneration and integration. The degradation products were also confirmed to be non-toxic, further supporting the biocompatibility of the material. In summary, the seawater collagen-chitosan IPN presents a promising candidate for degradable medical lumbar support pads, exhibiting a favorable combination of mechanical properties, biocompatibility, and controlled degradation.

6.2. Future Directions

Future research should focus on several key areas to further develop and validate the potential of seawater collagen-chitosan interpenetrating network (IPN) lumbar support pads. A primary direction involves optimizing the IPN composition to achieve a more finely tuned balance between mechanical strength, degradation rate, and biocompatibility. This includes investigating the effects of varying the ratios of collagen to chitosan, exploring different crosslinking agents and their concentrations, and incorporating other bioactive components such as growth factors or anti-inflammatory agents to enhance tissue regeneration and reduce post-operative inflammation. The impact of these compositional changes on the IPN's pore size, swelling ratio, and overall structural integrity should be thoroughly characterized.

Furthermore, comprehensive in vivo evaluations are crucial to assess the long-term performance and safety of the lumbar support pads. These studies should involve animal models that mimic human lumbar disc degeneration and instability, allowing for a realistic assessment of the pad's ability to provide mechanical support, promote tissue integration, and degrade in a controlled manner without eliciting adverse immune

responses. Histological analysis, biomechanical testing, and imaging techniques such as MRI and CT scans should be employed to monitor the pad's degradation behavior and its impact on the surrounding tissues over extended periods. The optimal implantation technique and potential for minimally invasive delivery methods should also be explored.

Finally, the unique properties of the seawater collagen-chitosan IPN material warrant investigation for other potential biomedical applications beyond lumbar support. Its biocompatibility, biodegradability, and tunable mechanical properties make it a promising candidate for tissue engineering scaffolds, drug delivery systems, and wound healing dressings. Exploring these alternative applications could significantly broaden the impact of this research and contribute to the development of novel therapeutic strategies for a range of medical conditions. The influence of factors such as the degree of deacetylation of chitosan (DDA) and the molecular weight (M_w) of collagen on the IPN's properties should also be further investigated.

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