The Blue Revolution in Healing: How Fish-Skin Collagen is Repairing the Human Body

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ABSTRACT

Fish-skin collagen is becoming a biomaterial that is not only safe, sustainable, and of clinical value but also relevant for various applications in wound management and regenerative medicine. Free from zoonotic risks and culturally acceptable, marine collagen has striking similarities to human Type I collagen and thus exhibits excellent biocompatibility and tissue integration. Evidence from in vitro, in vivo, and clinical studies indicates that the properties of marine collagen accelerate wound healing through improved re-epithelialization, promotion of fibroblast and keratinocyte activity, and enhanced extracellular matrix formation. Acellular fish-skin grafts have significantly reduced the healing time in donor sites and diabetic ulcers, assisted by the naturally retained omega-3 fatty acids providing antimicrobial and anti-inflammatory effects. Beyond skin wound management, marine collagen improves skin elasticity, actively supports bone regeneration, and contributes to anti-aging benefits. As up to 75% of fish biomass is usually discarded, its use in biomaterial production fully aligns with the principles of a circular bioeconomy through the conversion of by-products into high-value biomaterials. Altogether, these attributes make marine collagen a promising, sustainable alternative for biomedical and cosmetic advanced applications.

INTRODUCTION

For decades, collagen, the protein that gives strength and structure to our skin, bones, and connective tissues has been taken almost exclusively from land animals like cows and pigs. Making up nearly a third of the protein in every living organism, its uses span medical implants to common cosmetic creams. But relying on terrestrial animals has never been without complications. Collagen from cattle and pigs carries the risk of transmitting dangerous diseases such as BSE, and its use is restricted by cultural and religious boundaries around the world. These limitations have pushed scientists to find safer, universally accepted alternatives.

That search led back to the sea. The collagen derived from marine organisms, fish in particular, is naturally devoid of animal pathogens and hence bypasses the major health issue related to mammalian sources. Even more fascinatingly, fish collagen is mainly Type I collagen-the same type that predominates in human skin-is extremely biocompatible and is not likely to cause any kind of immune response. Its smaller molecular size also allows it to be absorbed and utilized more quickly by the body. What even makes that discovery more compelling is where the collagen comes from: waste. Almost 75% of each processed fish usually gets discarded, including skin, scale bones, and fins. Today, that overlooked material is being transformed into a valuable medical resource, turning what once polluted coastlines into a base for advanced wound care and tissue regeneration.

This shift from waste to wellness is more than scientific ingenuity; it's a signal of a new mindset-one in which medical advance and environmental responsibility actually go hand in hand. The benefits of marine collagen go far beyond the improved healing outcomes; it is a forerunner to a more sustainable, thoughtful approach to biotechnology to usher in a real "Blue Revolution" in regenerative medicine.

Advantages of Choosing Marine Sources

Fundamental concerns related to safety, ethics, and biology lie at the root of this shift in medical focus away from the conventionally terrestrial animals, such as cattle and pigs, to marine life. Collagen is a major structural protein of the body and forms important components that give strength and integrity to skin, bones, and connective tissues. Collagen sourced from mammals has dominated most pharmaceutical and cosmetic uses for many years and entails significant risks, including the transmission of dangerous diseases such as Bovine Spongiform Encephalopathy (BSE) and Foot-and-Mouth Disease (FMD). Terrestrial sources are also often restricted by religious or cultural beliefs.

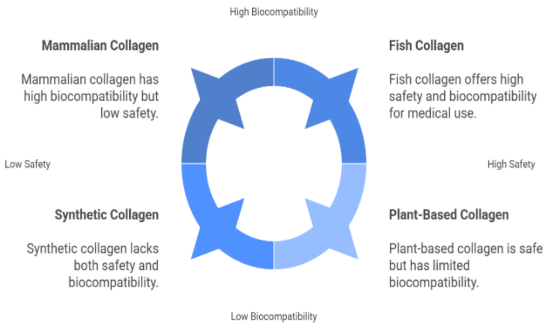

Fig.1 Advantages of Marine Collagen over Mammalian Collagen

Marine species present an exciting and realistic alternative. Collagen derived from fish is inherently safe since it is free from animal pathogens, hence safe from transmitting zoonotic diseases. This freedom from religious constraints and pathogens positions marine collagen as a favourable substitute in biomedical applications.

Apart from safety, fish collagen has the advantage of being extremely biocompatible with the human body. Fish skin is rich in Type

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I collagen, which is the most abundant form in human connective tissue. Such structural similarity ensures that the material is easily accepted and integrated by the human body. Importantly, marine collagen generally demonstrates low immunogenicity; it should, in theory, not elicit a harmful immune response and hence is a very good candidate for applications in both tissue engineering and direct wound dressing. In addition, during processing, fish collagen has a lower molecular weight than mammalian collagen, which is believed to facilitate easier and faster absorption by the body up to 1.5 times more efficiently upon oral administration.

Role of Fish Collagen in Wound Repair

In the event of serious injury, the body undertakes a complex, multi-stage repair process. Collagen is at the very center of this process, providing the literal scaffolding upon which new tissue is built. Fish collagen-based dressings protect the wound and actively hasten the healing process by directing and supporting cellular activity.

First, the material serves as an extremely effective natural structural scaffold. In the case of wound healing, this involves the generation of a porous, organized network that possesses mechanical strength and flexibility. This scaffold serves to provide an ideal structure for the transport of nutrients and oxygen, both critical for regeneration.

Marine collagen actively stimulates cellular mobilization and proliferation. It has been shown that this increases the migration and proliferation of fibroblasts and keratinocytes, which are considered the crucial cells to rebuild both the dermal and epidermal layers of the skin. For instance, grafts of fish skin have been found to be very porous, with greater passage allowed for these repair cells compared to some conventional treatments.

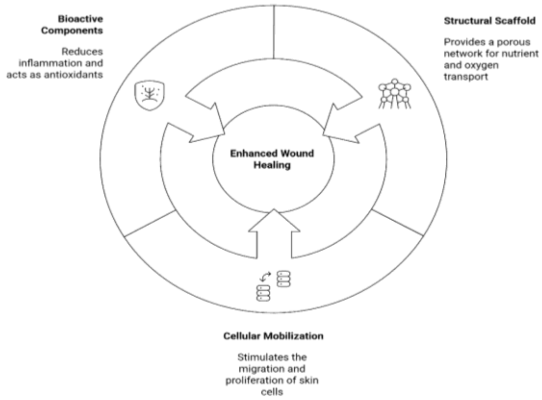

Fig. 2 Fish Collagen in Wound healing

Thirdly, materials derived from the marine environment bear potent bioactive components that optimize the healing environment. They can also reduce inflammation and act as antioxidants. Of critical importance in complex injuries, fish skin grafts often retain natural compounds such as omega-3 polyunsaturated fatty acids. These omega-3s serve as potent antibacterial agents, providing protection against common wound pathogens such as *S. aureus* and *P. aeruginosa*. By protecting physically, maintaining moisture, and stimulating cellular growth, collagen-based treatments provide a regenerative environment for faster tissue repair, enhanced vascularization (growth of new blood vessels), and tensile strength of the healed skin.

Fish Skin Grafts for Chronic Wounds and Burns

Acellular fish skin grafts, derived most often from Atlantic Cod or Nile Tilapia, are particularly effective xenografts for complex, non-healing wounds like chronic diabetic foot ulcers and burns (Menezes *et al*., 2020). In one skin graft donor site cohort study, the average healing time for patients treated with an acellular fish skin matrix was half that of the control patients treated with standard paraffin gauze - 31.5 days versus 67.9 days. Moreover, no patients in the FSG group contracted a local infection compared to 60% of the control patients. In other clinical studies conducted on chronic diabetic foot ulcers, FSGs were shown to heal significantly more wounds than the comparator, standard collagen alginate therapy.

The grafts also provide impressive results regarding deep trauma. In one study, a deep-thickness wound treated with FSG reduced in size after 30 days and was completely closed at 60 days, while providing good scar quality. This is attributed to the fact that fish skin retains the major bioactive components of Type I collagen and omega-3 fatty acids during processing, whereas these usually get eliminated in the harsh processing required for mammalian grafts.

Collagen based- Hydrogels and Sponges for Tissue Regeneration

Marine collagen can be processed into advanced biomaterials designed for precise tissue engineering. Collagen hydrogels, such as the one in this work derived from Nile tilapia skin, are highly valued for their porous structure, with interconnected pores normally ranging between 10-100 micrometres. This is crucial at a microscopic level, as it enables cell migration, which is important for the formation of new tissue. Such properties show the great potential of these hydrogels for application in tissue engineering in the future.

Further experiments prove the versatility of such formulations. The collagen sponges derived from fish scales, for example, Mrigal, accelerated the process of full-thickness wound healing in rat models (Pal *et al*., 2016). Even materials developed from more unusual sources, such as scaffolds generated from sea urchin food waste, have been shown to accelerate healing in larger animals such as sheep, showing reduced inflammation and enhanced keratinocyte migration compared with untreated wounds (Melotti *et al*., 2021).

Collagen Peptides for Wound healing

When it is degraded into small, highly soluble fragments known as peptides, collagen can be orally administered or delivered through sophisticated topical routes. Marine collagen peptides extracted from salmon and Nile tilapia skin have been orally administered to animals and found to accelerate the healing of cutaneous wounds. Such peptides accelerate this process by improving the availability of amino acids required for the synthesis of new proteins, thereby stimulating angiogenesis. Peptides derived from jellyfish have also been found to enhance cell migration and accelerate wound closure, while stimulating the expression of important healing factors involved in recruiting inflammatory cells and modulating the movement of fibroblasts.

Sustainable Use of Fish Waste

The most powerful narrative surrounding marine collagen pertains to its contribution toward a cleaner planet and circular economy. The sheer size of the global fish-processing industry means a large amount of raw material goes to waste. Typically, only some 25% of the total weight of fish is utilized for food products; up to 75% is left, including skins, bones, heads, and scales, discarded as by-products.

This huge, regular supply of "fishery waste" is now regarded as an ample and economically feasible source of high-quality Type I collagen. Through technologies being developed for the extraction and purification of this valued protein from by-products, researchers and industry are engaging in a "waste-to-value" practice that effectively limits environmental contamination while concurrently producing high-value health products. This value chain of sustainability resonates with consumers and investors in industry alike, and as such, this innovation in medical technology supports environmental stewardship through a process of limiting waste streams while reducing production costs.

CONCLUSION

The modern journey of marine collagen moves at a rapid pace, fuelled by proven efficacy and sustainable sourcing of the ingredient. Researchers are focused on transforming this versatile protein into sophisticated tools for regenerative medicine and tissue engineering.

It is expected that marine collagen will form the backbone of scaffolds, hydrogels, and complex clinical wound dressings in next-generation medical materials. For example, fish collagen scaffolds with reinforcement by other compounds demonstrated better mechanical properties, enhancing the formation of osteoblast cells responsible for bone healing, hence a potential in bone tissue engineering.

The fundamental benefits of marine collagen make it the safest, with a low risk of disease transmission, highly compatible with human tissue, and free from religious constraints, therefore making it the best alternative to conventional mammalian collagen sources. While fish collagen is known to have a somewhat reduced thermal stability compared to bovine sources, research is nevertheless ongoing in how to chemically or physically modify its structure to overcome these small drawbacks and ensure its suitability for all types of medical applications in the future. As observed by Gauza-Włodarczyk *et al*. 2017, the conversion of the ocean's immense biological by-products into advanced therapeutic materials means that marine collagen creates a resilient and ethical foundation in wound care and regenerative medicine globally.

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