SIEMIĄTKOWSKI, Robert, HABER, Mateusz, CZACHOR, Adrianna, KULA, Paula, JUŚKIEWICZ, Adam, GRELEWICZ, Olga, KUCY, Natalia, SERVAAS, Elwira and KOTULA, Alicja. Comparative Analysis of Collagen Supplementation Forms and Their Effects on Multiple Health Parameters. Journal of Education, Health and Sport. 2024;65:55474. eISSN 2391-8306.
https://dx.doi.org/10.12775/JEHS.2024.65.55474
https://apcz.umk.pl/JEHS/article/view/55474

The journal has had 40 points in Minister of Science and Higher Education of Poland parametric evaluation. Annex to the announcement of the Minister of Education and Science of 05.01.2024 No. 32318. Has a Journal's Unique Identifier: 201159. Scientific disciplines assigned: Physical culture sciences (Field of medical and health sciences); Health Sciences (Field of medical and health sciences).
Punkty Ministerialne 40 punktów. Załącznik do komunikatu Ministra Nauki i Szkolnictwa Wyższego z dnia 05.01.2024 Lp. 32318. Posiada Unikatowy Identyfikator Czasopisma: 201159. Przypisane dyscypliny naukowe: Nauki o kulturze fizycznej (Dziedzina nauk medycznych i nauk o zdrowiu); Nauki o zdrowiu (Dziedzina nauk medycznych i nauk o zdrowiu).© The Authors 2024;
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The authors declare that there is no conflict of interests regarding the publication of this paper.
Received: 01.09.2024. Revised: 10.09.2024. Accepted: 07.10.2024. Published: 09.10.2024.

Comparative Analysis of Collagen Supplementation Forms and Their Effects on Multiple Health Parameters

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ABSTRACT

Collagen, a key structural protein, is essential for maintaining the integrity of connective tissues such as skin, cartilage, tendons, bones. As natural collagen production decreases with age and is further compromised by environmental factors such as UV radiation and poor diet, collagen degradation accelerates, leading to conditions like wrinkles, joint stiffness, and decreased bone density. Collagen supplementation has gained widespread attention as a therapeutic intervention to counteract these effects. This review conducts a comprehensive comparative analysis of various forms of collagen supplementation, including hydrolyzed collagen, undenatured collagen, and gelatin, and their effects on a range of health outcomes. Hydrolyzed collagen, due to enhanced bioavailability, is associated with improvements in skin elasticity, hydration, joint pain relief, and muscle recovery, making it particularly valuable for aging populations and athletes. Undenatured type II collagen, on the other hand, modulates immune responses and shows potential in reducing inflammation and slowing the progression of degenerative joint diseases such as osteoarthritis and rheumatoid arthritis. Gelatin, while less bioavailable than hydrolyzed collagen, still supports skin and joint health when taken in larger quantities. This review also explores emerging evidence of collagen's beneficial effects on bone density, wound healing, and hair health, with marine-derived collagen showing promise in skin health due to its rapid absorption. Potential adverse effects, including mild gastrointestinal discomfort and rare allergic reactions, are discussed, emphasizing the importance of sourcing high-quality products. Overall, collagen supplementation, particularly hydrolyzed collagen peptides, offers significant therapeutic potential for improving skin, joint, and musculoskeletal health, but further research is required to define optimal dosages, formulations, and long-term safety for various populations.

INTRODUCTION

Collagen, the most abundant protein in the human body, is essential for maintaining the structure and function of connective tissues, including skin, tendons, cartilage, and bones. As collagen production declines with age, it contributes to visible signs of aging, joint degeneration, and reduced tissue elasticity [5]. This process is exacerbated by environmental factors, including UV exposure, poor diet, and smoking, all of which accelerate the degradation of existing collagen and inhibit the body's natural production [7]. Consequently,

many individuals experience issues such as wrinkles, loss of skin elasticity, joint stiffness, and decreased bone density, particularly as they age. This has led to growing interest in collagen supplementation as a preventive and therapeutic strategy to improve skin health, joint function, and overall musculoskeletal well-being [19]. Various forms of collagen supplements, such as hydrolyzed collagen, gelatin, and undenatured type II collagen, are widely available, each offering distinct potential benefits [10]. Hydrolyzed collagen, known for its high bioavailability, has been shown to improve skin elasticity and hydration while reducing joint pain in conditions like osteoarthritis [24, 25]. Moreover, it plays a role in muscle recovery and maintaining lean body mass, which is particularly relevant for aging populations and athletes. Meanwhile, undenatured type II collagen operates through immune modulation, showing promise in reducing inflammation in joint disorders such as rheumatoid arthritis [4]. It works differently from hydrolyzed collagen, targeting immune responses that attack cartilage, thereby slowing degeneration. Despite the growing popularity of these supplements, a comprehensive comparison of their effects on multiple health parameters—ranging from skin health and joint function to bone density and muscle mass—remains necessary [9]. This paper aims to conduct a detailed comparative analysis of various forms of collagen supplementation and their impacts on multiple health outcomes, informed by the latest scientific research [14].

Background: What is Collagen and Its Role in the Human Body

Collagen is a fundamental structural protein, representing between 25-35% of the total protein content in the human body [13]. As the primary component of the extracellular matrix (ECM), collagen plays a vital role in maintaining the structural integrity, elasticity, and mechanical strength of a wide range of tissues, including skin, tendons, ligaments, bones, cartilage, and blood vessels [8]. Its unique triple-helix configuration, composed of three polypeptide chains wound around each other, gives collagen its high tensile strength, which is essential for withstanding mechanical forces exerted on tissues during movement and stress [23]. This structure allows collagen to serve as a scaffolding for cells, enabling the tissue to remain resilient and functional under pressure. Among the 28 known types of collagen, types I, II, and III dominate, particularly in connective tissues, where they perform specific roles [12]. Type I collagen is predominantly found in the skin, tendons, and bones, where it contributes to rigidity and resistance to stretching, while type II collagen is mainly present in cartilage, ensuring joint resilience by maintaining the structural integrity of the articular cartilage [2, 21]. Type III collagen, which is less commonly discussed in the context of supplementation, is

vital for the integrity of hollow organs like blood vessels, and its decline is associated with vascular aging.

From the mid-20s onward, collagen degradation surpasses synthesis, leading to signs of aging such as wrinkles, joint pain, and decreased bone density [18]. This process accelerates with age, contributing to common degenerative conditions such as osteoarthritis and osteoporosis. Environmental factors such as UV radiation, smoking, and poor nutrition can accelerate collagen breakdown even further [7]. For example, exposure to UV rays directly damages collagen fibers in the skin, leading to a breakdown in the extracellular matrix and the formation of wrinkles. In response to these external and internal factors, the body's ability to repair and produce collagen diminishes, resulting in a gradual decline in tissue function and appearance. Clinical studies have demonstrated that regular intake of collagen supplements can improve skin hydration, elasticity, and reduce the appearance of wrinkles [17]. Collagen supplements are also associated with improved joint health, particularly in individuals with osteoarthritis, where they can reduce pain and enhance mobility by supporting cartilage repair and regeneration [3, 26]. Ongoing research continues to explore the broader effects of collagen on multiple health parameters, including muscle recovery, cardiovascular health, and gut integrity, further supporting the therapeutic potential of collagen in promoting overall well-being [28]. Some studies even suggest that collagen may play a role in reducing cellulite and improving nail strength, though these areas require further investigation.

Types and Forms of Collagen Supplementation

Collagen supplements are available in various forms, each designed to enhance bioavailability and efficacy. The most common forms include hydrolyzed collagen (collagen peptides), undenatured collagen, and gelatin [15]. Hydrolyzed collagen, also known as collagen peptides, is broken down into smaller peptides through enzymatic hydrolysis, which increases solubility and allows for efficient absorption in the gastrointestinal tract [6]. This form of collagen is particularly favored for its high bioavailability, with studies showing that hydrolyzed collagen is easily absorbed and supports skin elasticity, joint health, and muscle repair by promoting the synthesis of new collagen fibers [1, 11]. Once absorbed, these peptides travel through the bloodstream to the skin and other connective tissues, where they stimulate fibroblasts to produce more collagen and elastin. This process not only restores the skin's structural integrity but also helps in the repair of damaged tissues.

Undenatured collagen (UC-II) retains its native triple-helix structure and is primarily derived from chicken sternum cartilage. This form of collagen has a different mechanism of action compared to hydrolyzed collagen. Rather than being broken down into small peptides, UC-II works by modulating immune responses, particularly in the context of joint health [20]. Research suggests that undenatured collagen may help reduce symptoms of osteoarthritis by promoting immune tolerance to type II collagen, which is a key component of joint cartilage. By reducing the immune system's attack on cartilage, UC-II helps to slow the progression of cartilage degradation in conditions like osteoarthritis and rheumatoid arthritis. Gelatin, a partially hydrolyzed form of collagen, is less processed than collagen peptides but shares a similar amino acid profile [29]. Gelatin is primarily composed of denatured collagen and has lower bioavailability than hydrolyzed collagen. However, it still supports joint and skin health, particularly when consumed in larger doses. Gelatin is commonly used in food products like gummies and jellies, making it a convenient, albeit less potent, form of collagen supplementation. Recent innovations in marine-derived collagen, sourced from fish, offer a higher absorption rate compared to bovine or porcine collagen, making it particularly beneficial for skin health and wound healing [30]. Marine collagen is predominantly composed of type I collagen, which is most effective in promoting skin elasticity and hydration. Due to its smaller molecular weight, marine collagen is absorbed more rapidly, making it an appealing option for those seeking quick results. Furthermore, marine collagen is considered more sustainable and ethical, as it utilizes fish by-products that would otherwise go to waste.

Each form of collagen supplementation—whether hydrolyzed, undenatured, or gelatin—differs in its molecular structure, absorption, and physiological impact. The choice of form depends on the targeted health outcome, such as skin rejuvenation, joint support, or muscle repair, with hydrolyzed collagen being the most versatile and widely researched [27]. As the field of collagen supplementation continues to evolve, new forms of collagen, including plant-based alternatives that aim to mimic the effects of animal-derived collagen, are being explored, though these products are still in their infancy and require more clinical validation.

Collagen form	**Source**	**Molecular Structure**	**Bioavailability**	**Mechanism of action**	**Main Health Benefits**	**Common Dosages**
Komórka Hydrolyzed Collagen (Peptides)	**Bovine, Porcine, Marine**	**Small peptides, broken down**	High	**Stimulates fibroblasts to produce new collagen**	**Improves skin elasticity, joint health, muscle repair**	**2.5-15 g/day**
Undenatuated Collagen (UC – II)	**Chicken Sternum Cartilage**	**Native triple-helix**	Moderate	**Modulates immune response to reduce inflammation**	**Reduces symptoms of osteoarthritis, supports joint health**	40 mg/day
Gelatin	**Bovine, Porcine**	**Partially hydrolyzed**	Low	**Provides amino acids for collagen synthesis**	**Supports joint and skin health**	5-10 g/day
Marine-Derived Collagen	Fish	**Small peptides, broken down**	Very Hgh	**Stimulates fibroblasts, particularly effective for skin**	**„Promotes skin health and wound healing**	2,5-10 g/day

Effects of Collagen Supplementation on Hair and Skin

Collagen supplementation has been associated with significant benefits for both hair and skin health, with numerous studies demonstrating its role in improving the structural integrity of the dermal layers and hair follicles [13]. The amino acids found in collagen, such as proline, hydroxyproline, and glycine, are essential for the production of keratin, the primary protein that forms the structure of hair, as well as the epidermis [16]. By providing the necessary building blocks for keratin production, collagen supplementation has been shown to improve hair thickness, strength, and texture, reducing breakage and promoting overall hair health. Moreover, collagen's antioxidant properties, particularly those found in marine-derived collagen, may protect hair follicles from oxidative stress, which is a key factor in hair thinning and hair loss. Oxidative stress, caused by free radicals from environmental factors such as UV exposure, pollution, and poor nutrition, can damage the cells within hair follicles, leading to premature hair loss or thinning. By neutralizing free radicals and creating a healthier scalp environment, collagen supplementation may contribute to stronger, more resilient hair, potentially improving hair density and growth over time [25]. Additionally, collagen's hydrating properties can help improve the elasticity and moisture balance of the scalp, further promoting a healthier environment for hair growth. However, more clinical trials are needed to definitively establish collagen's role in enhancing hair growth and to understand the long-term benefits of supplementation on hair health.

For the skin, collagen plays an even more critical role as it is one of the major components of the dermal extracellular matrix, which provides the skin with firmness, elasticity, and smoothness [30]. As collagen production naturally declines with age, the skin becomes thinner, less elastic, and more prone to wrinkling and sagging. Collagen supplementation, especially in hydrolyzed form, has been shown to counteract these age-related changes by stimulating fibroblasts to produce more collagen and elastin, two key proteins that maintain the structural integrity of the skin [22, 5]. Several clinical studies have demonstrated that oral collagen supplementation can significantly improve skin hydration, elasticity, and texture, reducing the appearance of fine lines and wrinkles. For instance, a study by Proksch et al. (2014) found that daily intake of collagen peptides led to noticeable improvements in skin

elasticity and moisture levels in women aged 35 and older, who were experiencing early signs of aging [6]. The peptides were absorbed into the bloodstream, distributed to the skin, and integrated into the existing collagen network in the dermis, promoting regeneration and repair of skin tissues. This process not only rejuvenates the skin but also enhances its natural barrier function, improving its resistance to environmental damage.

Additionally, collagen supplements possess antioxidant properties that help protect the skin from environmental stressors such as UV radiation and pollution, which are known to accelerate the aging process by generating free radicals that damage collagen fibers and other proteins in the skin [9, 10]. By neutralizing free radicals and supporting the natural regenerative processes of the skin, collagen supplementation may help prevent further damage and slow the progression of visible aging. In some cases, collagen supplementation has been linked to improvements in skin conditions such as dryness, hyperpigmentation, and even acne, though these effects are less well-documented and require further research. Overall, the combined effects of enhanced collagen production, improved hydration, and antioxidant protection make collagen supplementation a promising strategy for maintaining skin health, particularly in aging populations or individuals exposed to high levels of environmental stress.

Effects of Collagen Supplementation on Bones and Joints

Collagen supplementation has attracted considerable attention for its potential benefits in promoting bone and joint health, especially in addressing degenerative conditions such as osteoarthritis and osteoporosis [17]. Collagen, the most abundant protein in the extracellular matrix of connective tissues, plays a critical role in maintaining the structural integrity and mechanical properties of cartilage, bones, tendons, and ligaments. As natural collagen production declines with age, this contributes to joint degeneration and decreased bone mineral density (BMD), both of which are risk factors for osteoarthritis, fractures, and associated joint pain [1, 7]. This decrease has prompted interest in oral collagen supplementation as a therapeutic strategy to mitigate these processes [8].

Clinical trials have shown that hydrolyzed collagen peptides, owing to their increased bioavailability, can support joint and bone health. Hydrolyzed collagen is absorbed in the small intestine and distributed to connective tissues, where it stimulates the production of endogenous collagen by chondrocytes and osteoblasts. Studies indicate that collagen

supplementation can reduce osteoarthritis symptoms, including joint pain and stiffness, by enhancing cartilage regeneration and preventing further degradation. For example, a randomized controlled trial by Clark et al. (2008) involving athletes with activity-related joint pain reported significant improvements in joint function and pain reduction after 24 weeks of collagen supplementation, compared to a placebo group [9]. This effect may be attributed to the upregulation of extracellular matrix components, such as glycosaminoglycans and type II collagen, which are essential for cartilage integrity [3, 21].

In addition to joint health, collagen supplementation has been shown to positively affect bone density, particularly in postmenopausal women who are at increased risk of osteoporosis [18]. A study by König et al. (2018) demonstrated that daily collagen supplementation significantly increased BMD and improved bone formation markers such as procollagen type I N-terminal propeptide (PINP), a biomarker of bone formation, in postmenopausal women [4]. These findings suggest that collagen enhances bone metabolism by promoting osteoblast activity and improving the balance between bone resorption and formation, potentially reducing the risk of fractures in osteoporotic populations [25]. Collagen's anti-inflammatory properties may further contribute to its beneficial effects on joint health. In osteoarthritic conditions, pro-inflammatory cytokines such as interleukin-1β (IL-1β) and tumor necrosis factor-α (TNF-α) play a critical role in cartilage breakdown. Research indicates that collagen peptides may downregulate these cytokines, thereby reducing inflammation and protecting cartilage from further degradation [26]. Bello and Oesser (2006) reviewed multiple studies demonstrating the anti-inflammatory effects of collagen peptides, suggesting that regular supplementation may slow the progression of osteoarthritis and other degenerative joint diseases [28].
While these results are promising, further research is needed to optimize collagen supplementation for bone and joint health. Bioavailability studies indicate that different forms of collagen (e.g., hydrolyzed vs. undenatured) exhibit variations in absorption and distribution, suggesting that the specific form consumed may impact its efficacy [7]. Additionally, the optimal dosage, frequency, and duration of supplementation remain subjects of ongoing research. Preliminary evidence suggests that daily doses of 5 to 15 grams are effective, but individualized protocols based on age, baseline bone density, and activity level may enhance outcomes.

Effects of Collagen Supplementation on Wound Healing

Collagen plays a central role in wound healing by providing structural support, facilitating cellular migration, and promoting the synthesis of extracellular matrix (ECM) components [29]. Collagen supplementation, both oral and topical, has been investigated for its potential to enhance wound healing, particularly in chronic and surgical wounds. Hydrolyzed collagen peptides are easily absorbed and distributed to wound sites, where they stimulate fibroblast activity and collagen synthesis. In a study by Choi et al. (2013), oral administration of collagen tripeptides enhanced re-epithelialization, increased collagen synthesis, and improved the mechanical properties of newly formed skin tissue in a murine wound healing model [30]. Beyond structural support, collagen supplementation may modulate the inflammatory phase of wound healing, which, if prolonged, can lead to chronic wounds. Collagen peptides have been shown to reduce levels of pro-inflammatory cytokines such as TNF-α and interleukin-6 (IL-6), creating a more favorable environment for tissue repair [19]. Xu et al. (2019) found that collagen hydrolysates reduced inflammatory markers in UV-damaged skin, suggesting a potential role for collagen in managing inflammatory wounds [7]. Additionally, collagen supplementation has been linked to improved granulation tissue formation, which is essential for wound closure. Schmidt et al. (2015) found that collagen-treated patients with chronic venous leg ulcers demonstrated significantly faster wound healing and enhanced granulation tissue formation [22]. In surgical patients, collagen supplements have also been shown to enhance recovery by promoting faster closure of incisions and reducing scarring. Though more research is needed to fully understand the long-term impact of collagen on wound healing, these preliminary results suggest that collagen could be an important therapeutic tool for managing both acute and chronic wounds.

Collagen supplementation and physical activity

Collagen supplementation has gained popularity among physically active individuals who are not professional athletes but engage in regular physical activities such as running, yoga, strength training, or endurance sports. In this population, collagen is valued for its potential to improve muscle recovery, protect joints, and prevent injuries. Research has shown that regular consumption of hydrolyzed collagen can support joint health, which is particularly beneficial for individuals exposed to moderate physical exertion, reducing the risk of joint pain and mobility issues [3, 19]. Active individuals, especially those involved in weight-bearing exercises or high-impact activities, often experience joint overload, particularly in the knees, hips, and ankles, which can lead to pain and decreased performance. Studies have

demonstrated that collagen helps in cartilage regeneration, reducing joint pain and improving joint function, even after intense physical activity, thereby lowering the risk of injury [6, 19].

In addition to joint support, collagen supplementation may also aid in muscle recovery. The amino acids found in collagen, such as glycine and proline, are critical for the repair of muscle tissue and tendons, which can be damaged during exercise. Research has indicated that individuals who supplement with collagen experience faster recovery times after workouts, allowing for more frequent and intense training sessions without chronic muscle soreness or fatigue [9, 13]. Collagen not only aids in muscle recovery but may also enhance tendon strength, which is crucial for individuals engaging in activities that require dynamic movements and strength, such as weightlifting or long-distance running [11]. In studies by Jerger et al. (2022), regular collagen supplementation combined with resistance training improved the properties of the Achilles tendon, reducing the risk of injury and enhancing stability during strenuous exercise [13].

Interestingly, collagen may also support tissue recovery after minor injuries, such as microtears in muscles, which occur as a natural result of intense physical activity. These microtears can delay recovery and contribute to delayed onset muscle soreness (DOMS). Studies have noted that individuals who supplement with collagen report reduced symptoms of DOMS and a quicker return to full activity after heavy training sessions, enabling them to engage in more consistent exercise without extended downtime for recovery [1, 6].

In summary, collagen supplementation among physically active individuals who are not professional athletes provides notable benefits, including improved joint health, enhanced muscle recovery, and protection against minor injuries. Research suggests that regular collagen intake may not only reduce joint and muscle pain but also improve athletic performance by facilitating faster recovery and reducing the risk of injury, allowing for more effective and sustained participation in various forms of physical activity [19, 27].

Adverse Effects of Collagen Supplementation

Although collagen supplementation is generally considered safe, especially when taken within the recommended dosage, there are some potential side effects that users should be aware of. Mild gastrointestinal disturbances, such as bloating, diarrhea, or nausea, have been reported in

some cases, though these effects tend to be rare and dose-dependent [6]. It is possible that the digestive system may react to the sudden introduction of a new protein source, especially in higher doses, causing temporary discomfort. However, these side effects are usually mild and subside once the body adjusts to the supplement. Schadow et al. (2019) reported minimal adverse effects in most participants, with only a small subset experiencing transient digestive issues that did not require withdrawal from the study [18].

More concerning, though relatively rare, are allergic reactions to collagen derived from animal sources, such as bovine, porcine, or marine collagen. Individuals with pre-existing allergies to these species may experience symptoms ranging from mild skin rashes to more severe reactions, such as difficulty breathing or anaphylaxis. Salgado et al. (2019) reported cases of allergic reactions to marine collagen in individuals with fish allergies, underscoring the importance of carefully selecting the source of collagen, particularly for those with known food sensitivities [12]. Users with allergies to specific animal proteins should consult a healthcare professional before beginning collagen supplementation and consider plant-based alternatives if available.

Another potential concern with marine-derived collagen is contamination with heavy metals, particularly mercury and lead, due to environmental pollution in oceans. Studies have shown that marine collagen products can contain trace amounts of these harmful substances, which could accumulate in the body over time if consumed in large quantities or for prolonged periods. Wang et al. (2020) found varying levels of heavy metals in marine collagen products, suggesting the need for stringent quality control and better transparency from manufacturers regarding sourcing and purification processes [14]. To minimize the risk of contamination, consumers are advised to choose collagen supplements from reputable brands that test their products for heavy metals and provide clear information about sourcing and safety standards.

Overall, while collagen supplementation is generally well-tolerated and safe for most people, it is important to be mindful of potential side effects and allergic reactions, particularly in individuals with sensitivities to animal-derived proteins or a history of digestive issues. Selecting high-quality, certified products can help reduce the likelihood of contamination and adverse reactions.

Discussion

The growing popularity of collagen supplementation can be attributed to its wide range of potential health benefits, including improvements in skin elasticity, joint function, bone

density, and even wound healing [15]. Hydrolyzed collagen peptides, in particular, have demonstrated significant bioavailability and efficacy across multiple health parameters, making them the most commonly researched and widely recommended form of collagen supplementation [6]. While the evidence supporting collagen's benefits is promising, it is also important to recognize that not all individuals may experience the same results. Factors such as age, baseline collagen levels, activity level, and overall health can influence the efficacy of collagen supplements. For example, older individuals with more advanced collagen degradation may require higher doses or longer supplementation periods to observe noticeable improvements in skin or joint health, whereas younger individuals with healthy collagen levels may experience more subtle benefits.

Moreover, variations in collagen source, type, and dosage can impact the outcomes of supplementation. Marine-derived collagen, for instance, has been shown to have a higher absorption rate than bovine or porcine collagen due to its smaller molecular weight, making it particularly beneficial for skin health and wound healing [27]. However, it may not be as effective for joint or bone health, where type II collagen from chicken sternum or bovine sources may offer more targeted benefits. Additionally, the presence of other bioactive compounds in collagen supplements, such as vitamin C, hyaluronic acid, or glucosamine, can further enhance the absorption and efficacy of collagen, particularly in joint and skin health. These combinations may work synergistically to improve outcomes, though more research is needed to fully understand the optimal formulations and dosages for different health conditions [3, 9].

Despite the promising results from clinical trials, it is also important to note that collagen supplementation is not a "quick fix." The body's collagen production and repair processes take time, and individuals may need to take supplements consistently for several months before noticing significant changes. Additionally, while collagen can support the body's natural healing processes, it cannot fully reverse the effects of aging or repair extensive damage caused by long-term environmental exposure, poor diet, or other lifestyle factors. Collagen supplements should be viewed as part of a comprehensive approach to health and wellness, which includes a balanced diet, regular exercise, and proper skincare routines.

Conclusions

Collagen supplementation presents a promising strategy for enhancing skin elasticity, joint health, and bone density, particularly as part of a preventive or therapeutic approach to combat the effects of aging and degenerative diseases [22]. Hydrolyzed collagen peptides, in particular, have shown significant efficacy in improving skin hydration, reducing wrinkles, and supporting joint cartilage repair, making them an attractive option for individuals seeking to maintain their physical health and appearance. While collagen supplements are generally safe and well-tolerated, attention must be paid to potential side effects, allergies, and product quality. Users with known allergies to animal proteins should exercise caution and consult a healthcare professional before starting collagen supplementation. Additionally, choosing high-quality, certified products can help mitigate the risk of contamination with heavy metals, particularly in marine-derived collagen.

As research into collagen supplementation continues to evolve, further studies are needed to determine the optimal dosages, formulations, and long-term safety for different populations, particularly in individuals with specific health conditions or dietary needs. Large-scale clinical trials examining the effects of collagen supplementation over extended periods are also necessary to fully understand the long-term benefits and potential risks associated with regular collagen intake. Overall, collagen supplements offer a valuable tool for supporting the body's natural collagen production and promoting overall health and well-being, though they should be used as part of a broader, balanced approach to health.

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All authors have read and agreed with the published version of the manuscript.

Founding Statement: The study did not receive funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflict of Interest Statement: The authors declare no conflicts of interest.

Acknowledgments: Not applicable.

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