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Review Article

Bioactive Peptides in Aging, Cancer Therapy, and Related Disorders: Current Advancements and Future Directions

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Abstract

Bioactive peptides have emerged as potent therapeutic molecules with applications spanning aging, cancer, and related chronic diseases. Derived from food, marine, and synthetic sources, these peptides demonstrate antioxidative, anti-inflammatory, and regenerative effects, and they are increasingly being recognized for their potential in modulating hallmarks of aging and cancer progression. Recent research emphasizes their ability to target oxidative stress, genomic instability, cellular senescence, and immune evasion mechanisms. However, limitations such as poor bioavailability, stability, and production costs constrain their clinical translation. Advancements in nanotechnology and computational biology offer promising solutions, including peptide-functionalized nanoparticles and machine learning-driven peptide discovery. This review consolidates recent insights into the molecular mechanisms, therapeutic potential, and translational challenges of bioactive peptides, with a particular focus on their roles in aging regulation and cancer therapy. Recent advances in nanotechnology, computational biology, and peptide engineering have significantly enhanced their bioavailability and therapeutic potential. However, challenges remain in terms of clinical translation, stability, and cost-effective production. This review consolidates the mechanistic roles, therapeutic applications, and future perspectives of bioactive peptides in aging and cancer, with an emphasis on emerging research and opportunities in the world.

Keywords: *Bioactive Peptides; Aging; Cancer; Nanotechnology; Mitochondrial Dysfunction; Oxidative Stress; Peptide Therapeutics*

Introduction

Aging and cancer share common molecular pathways characterized by genomic instability, deregulated nutrient sensing, and impaired cellular repair mechanisms [1]. As life expectancy rises globally, age-related diseases and cancer incidence continue to increase, emphasizing the need for safer and more efficient therapeutic interventions. Bioactive peptides-short amino acid chains (2 - 20 amino acids) derived from natural or synthetic sources-offer therapeutic advantages owing to their high specificity, low immunogenicity, and tunable biological activity [2-4]. These peptides exhibit diverse functions, including antioxidant, anti-inflammatory, antimicrobial, and signaling activities [5-8].

Peptides are short chains of amino acids, and prior studies suggest they may support cancer treatment, may slow some age-related changes, and can act as bioactive compounds with therapeutic activity [2-4,9,10]. Peptides can be useful drug candidates because, relative to many conventional small-molecule drugs, they often act on more specific targets, tend to have lower toxicity, and can work through a range of biological mechanisms [2,10,11]. Bioactive peptides are now widely studied as therapeutic molecules, with reported uses in aging, cancer, and other chronic diseases [3,9,10]. These peptides can be obtained from foods, marine organisms, or made synthetically. Research reports that they show antioxidant, anti-inflammatory, and tissue-repair activity, and suggests they may influence core biological features related to aging and to cancer growth and progression [2,4,9,12]. Recent studies suggest they can act on oxidative stress, genomic instability, cellular senescence, and pathways that let cells evade immune responses [9-11,13]. Even so, issues like low bioavailability, limited stability, and high production costs still limit their move into clinical practice [3,4,9,14]. Recent work in nanotechnology and computational biology suggests workable approaches, such as peptide-functionalized nanoparticles and machine-learning methods for finding new peptide candidates [15-17].

This review brings together recent work on how bioactive peptides act at the molecular level, what they might offer as treatments, and the main issues in moving them from lab studies to clinical use, with a focus on their roles in aging control and cancer therapy [3,9-11]. Recent work in nanotechnology, computational biology, and peptide engineering has improved peptide bioavailability and supports their use as therapies [14-16]. Even so, challenges remain for clinical translation, long-term stability, and cost-effective production [3,4,14]. This review brings together current evidence on how bioactive peptides act at the mechanistic level, how they may be applied in treatment for aging and cancer, and which questions should guide future research [2,3,9-11].

This review pulls together what recent studies report about natural and synthetic peptides used in cancer treatment, anti-aging research, and other medical uses. It reviews the biological mechanisms behind these peptides, their possible clinical uses, and their limits, with a focus on Bangladesh, where peptide research is starting to take shape but still runs into practical and funding constraints. This paper reviews practical ways to improve peptide stability, increase bioavailability, and support delivery to specific tissues, then outlines next steps that may come from nanotechnology, machine learning, and peptide engineering. In sum, peptides offer a flexible basis for new treatments, and continued research could lead to therapies that work well, cost less, and suit local clinical needs.

The study focuses on peptides as peptide therapeutics for cancer therapy and aging, with attention to anti-aging peptides. It also considers how nanotechnology-based drug delivery could shape peptide treatments in Bangladesh, where access, cost, and local research capacity matter for real-world use. This opening section explains what the study is about and why it matters. It gives the background needed to understand the topic, states the main question the paper addresses, and outlines the approach taken. It also clarifies the scope of the work and briefly notes how the rest of the paper is organized. Cancer and aging remain two of the most pressing health issues worldwide. Cancer remains a major cause of illness and death worldwide, with millions of new diagnoses and deaths reported each year [18].

Aging and the biological hallmarks of aging

Aging refers to a gradual biological process in which cells and tissues lose function over time, leading to a steady decline in how well the body maintains and repairs itself. Key processes include oxidative stress driven by reactive oxygen species (ROS), impaired mitochondrial function, long-term inflammation, and DNA damage [19]. Together, these processes are linked to common features of aging, such as skin wrinkling, poorer cognitive performance, and declining organ function [19]. With age, the skin shows clear biological changes, including lower collagen levels, higher matrix metalloproteinases (MMPs), and weaker antioxidant defenses [14,19,20]. As the brain ages, thinking and memory often decline, and the risk of diseases like Alzheimer's rises, in part because oxidative stress, mitochondrial problems, and inflammation become more common [19].

Aging is also linked to the build-up of cellular damage, a decline in normal biological function, and a higher risk of chronic diseases [19] (Figure 1). Standard cancer treatments such as chemotherapy, radiotherapy, and surgery can cause serious side effects and may not work well, especially when the disease is at an advanced stage. Even so, current approaches to slow aging and treat age-related disorders still produce only modest results. Peptides are short chains of amino acids, usually about 2 to 100 residues long, and they are being studied as potential tools for both cancer treatment and research on aging [19,21,22]. They may come from natural sources, such as foods, venoms, or marine organisms, or they may be made through chemical synthesis [22,23]. Because they are small, bind to specific targets, and can interact with biological molecules, they can selectively change cellular pathways involved in apoptosis, immune activity, oxidative stress, and inflammation [19,21,22] (Figure 2). Peptides can also be used in drug delivery and molecular imaging, which broadens their use as multifunctional therapeutics [15,18].

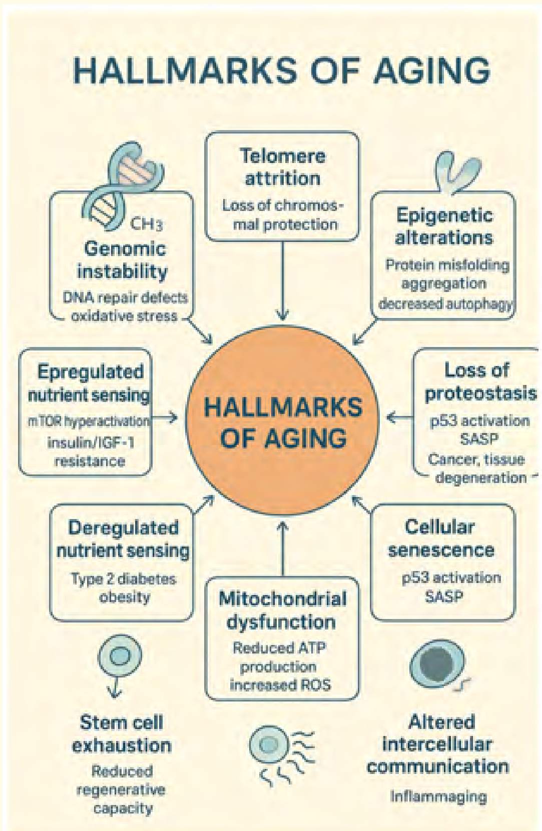

Figure 1: *Hallmarks of aging showing genomic instability, telomere attrition, mitochondrial dysfunction, and cellular senescence, along with bioactive peptide interventions. The schematic illustrates the nine recognized hallmarks of aging as described by López-Otín., et al. [30], including genomic instability, telomere attrition, epigenetic alterations, loss of proteostasis, deregulated nutrient sensing, mitochondrial dysfunction, cellular senescence, stem cell exhaustion, and altered intercellular communication. Each hallmark represents a key biological process contributing to the progressive functional decline associated with aging. The figure highlights underlying molecular pathways such as DNA repair defects, oxidative stress, mTOR hyperactivation, p53 activation, and inflammation ("inflammaging"), which together drive cellular and systemic aging.*

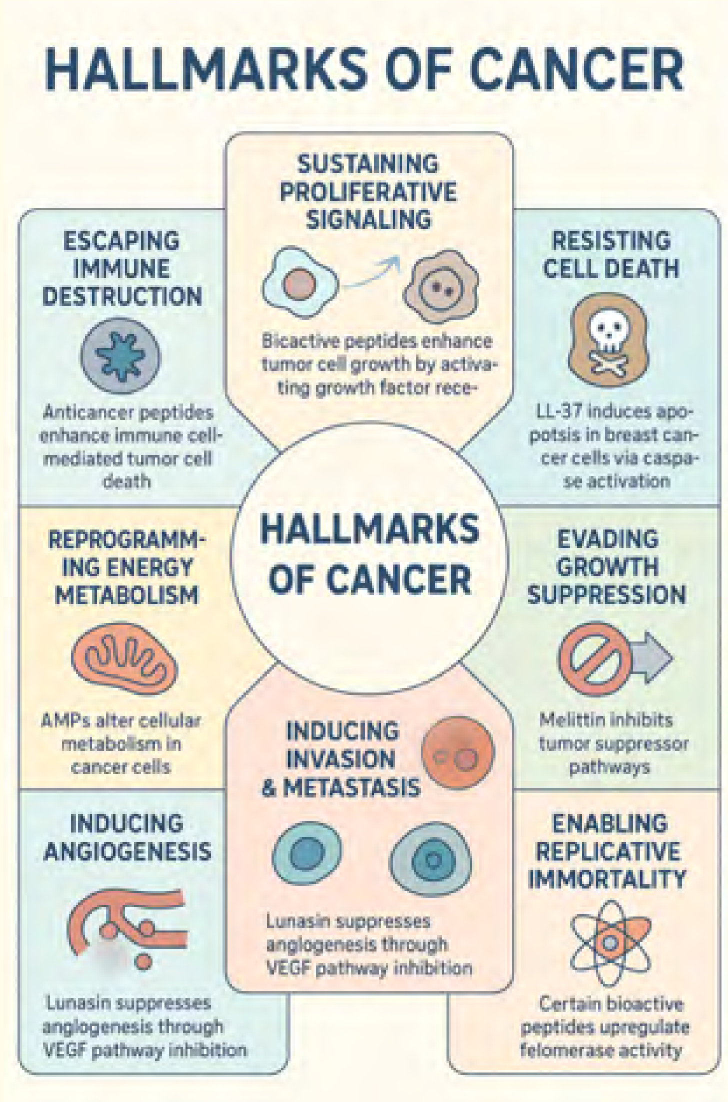

Figure 2: *Hallmarks of cancer illustrating peptide mechanisms targeting angiogenesis, apoptosis induction, and immune modulation. This illustration depicts the classical hallmarks of cancer, including sustaining proliferative signaling, resisting cell death, evading growth suppression, enabling replicative immortality, inducing angiogenesis, activating invasion and metastasis, reprogramming energy metabolism, and escaping immune destruction. The figure integrates mechanistic examples of bioactive and anticancer peptides (ACPs) that modulate these pathways-for instance, LL-37 promoting apoptosis via caspase activation, melittin inhibiting tumor suppressor pathways, and lunasin suppressing angiogenesis through VEGF pathway inhibition. Collectively, these mechanisms underscore the therapeutic potential of peptides as targeted modulators of tumor growth, invasion, and immune evasion.*

Several other organs, such as the lungs, liver, kidneys, and heart, also show a decline in function that appears to be driven by the same kinds of molecular mechanisms. In aging research, peptides are often studied because they may influence several biological markers that are commonly linked with aging. Diet-derived bioactive peptides have been reported to increase antioxidant enzyme activity, lower inflammation, and aid DNA repair [14,19]. In one study, Pep 14 lowered senescence markers and reduced SASP release in skin cells, shifting gene expression toward a younger pattern and decreasing estimated biological skin age [14]. In the brain, peptides such as carnosine and lab-made analogs may help limit oxidative damage and, in turn, support cognitive functions [19]. In other organs, peptides such as GHK-Cu, adropin, and SBT-20 have been reported to lower oxidative stress and inflammation and to limit tissue damage [19]. The purpose of this research is to define the problem clearly and explain why it matters in the context of existing studies. The study aims to answer a focused set of questions and, where suitable, test specific expectations about what may be found. It also seeks to fill a clear gap in prior work by gathering and analyzing evidence in a way that can support clear conclusions. In doing so, the research sets out what the study will cover, what it will not cover, and how the findings may inform future research or practice. This manuscript surveys the current research on peptides as therapeutic agents in cancer and aging. It outlines how these processes work in the body, where they can be used in clinical settings, and what their main limitations are.

Mechanistic role of bioactive peptides

One of the best roles for peptides is that it can act directly like an anti-cancer agents. Some peptides can disrupt cell membranes, interfere with signals that control cell growth, or block protein interactions that cancer cells rely on [2-4,10,24]. Others peptides are used as inhibitors of enzymes that support tumor growth [2,19,21-23,25,26]. Peptides can also support the immune response, for example they can act as vaccine components that present tumor-related fragments to immune cells so the body can better recognize cancer [11,27].

Biopeptides are also widely used as delivery tools. A peptide that binds to a tumor marker can be attached to a chemotherapy drug, a toxin, or a radioactive labeled compound. The peptide acts like an address label that helps the attached agent reach cells that carry that marker [10,15,16]. Related approaches include peptide-based imaging, where peptides carry tracers that help locate tumors or track treatment response [10,16]. There are still practical limitations. Many peptides break down quickly in the body and may not reach the tumor in enough quantity [2,14]. Researchers address this with changes such as using non-natural amino acids, adding protective chemical groups, or packing peptides into nanoparticles or other carriers [14-16].

In current research, the main goal is to balance target binding, stability in blood, safe clearance from the body, and a clear benefit over existing treatments. Peptides are now widely studied as flexible effective tools for treating cancer. Anticancer peptides (ACPs) can preferentially act on cancer cells while leaving most healthy cells more or less un-affected, which may lower toxicity when compared with chemotherapy and radiotherapy [18,21]. They can cause cancer cells to die through several routes, including apoptosis, membrane disruption, DNA damage, reduced angiogenesis, and changes in immune responses [18,21]. ACPs may also penetrate tumors more readily and may lower the chance that drug resistance develops [18,21]. Researchers have examined peptide-based interventions in several cancer types. In lung cancer models, peptides such as AC-P19M have been reported to reduce cell growth, movement, and other invasive behaviors as responses [18]. In breast cancer models, peptides such as D-LAK-120A have been used to trigger apoptosis and limit metastatic spread [18]. In colorectal cancer models, peptides such as BMAP-27 and DTT-205 have been reported to reduce cell proliferation and support tumor regression [18].

Peptides have also been reported to work against prostate, gastric, hepatocellular, melanoma, brain, and osteosarcoma cancers [16,18,26]. Peptides are now being studied as part of cancer immunotherapy. In such cases, they can be used to train the immune system to recognize tumor-related targets and support a more focused immune response. Peptide vaccines can trigger both antibody and T cell immune responses by aiming at antigens that are unique to tumors or commonly present on tumor cells. Anticancer peptides may trigger immune cell activity and slow tumor growth. In drug delivery, peptide-based carriers such as cell-penetrating peptides, homing peptides, and self-assembling nanostructures are often used to improve how precisely treatment reaches the tumor site [15].

In Bangladesh, cancer is still a major public health problem, with high rates of new cases and deaths, while peptide-based treatments remain scarce [26]. This research is held back by limited access to advanced peptide synthesis labs, very few clinical trials, and restricted availability of nanotechnology and drug delivery platforms. This points to the need to strengthen local capacity, more expanded and well-funded international collaborations, and develop lower-cost production approaches so that peptide-based options can be used more widely in cancer treatment [26].

How peptides shape aging research and its effects

Peptides are studied for many uses that go well past cancer treatment, including antimicrobial work, metabolic disease research, and drug delivery systems. During aging, bioactive peptides can slow the onset of cellular senescence, support antioxidant defenses, and lessen inflammatory signaling. Skin-aging peptides can support collagen production, reduce the activity of MMPs, and help limit UV-related damage, which may help maintain a more youthful-looking skin appearance [14,19,20]. Senotherapeutic peptides, including Pep 14, have been reported to lower biological age in human skin models and to support DNA repair, suggesting the possible value for both medically and also in cosmetologist [14]. In the brain, peptides may reduce oxidative stress, the anti-oxidants limit iron buildup, increase the expression of neurotransmitter receptors, and help regulate gut microbiota, which may support better cognitive function [19]. Peptides may also support organs such as the lungs, liver, kidneys, and heart by lowering oxidative stress and inflammation, which may slow organ-specific aging processes [19]. Marine-derived peptides have been reported to inhibit enzymes such as DPP4, which may support metabolic health and aspects of immune regulation [5].

One of the core limited issues is the stability of the peptides. Many peptides break down quickly in blood and tissues because enzymes treat them like food or as source of nutrition. That short life-time can lead to frequent dosing, and for many products that ends up being injections rather than tablets. As oral dosing is hard because the stomach acid and digestive enzymes can destroy peptides before they reach the bloodstream, and even if they survive, they may not cross the gut wall well. Rapid kidney clearance is another common problem, especially for smaller peptides, so the drug may leave the body before it can do enough work [6].

The formulation and manufacturing of such framework create their own set of challenges. Peptides can stick to surfaces, clump together, or lose their shape during storage, shipping, or after mixing. Some require cold storage, which complicates supply chains and limits access in stages of manufacture. On the production side, longer or more complex peptide sequences can increase cost and make it harder to keep batch-to-batch quality consistent which may affect the final doses. There is also the risk of unwanted immune responses, especially with repeated dosing or modified sequences, which can reduce benefit or cause side effects [6,7].

In research and development, these constraints push teams toward chemical changes, carrier systems, or dosing strategies that keep the peptide intact long enough to act. Those fixes can help, but they also add new questions about safety, scaling, and how the drug behaves in real patients over time. Even though peptides can be useful, they are often limited by low stability in the body, quick enzyme-driven breakdown, poor bioavailability, and expensive manufacturing [16,17,26,27]. In cancer treatment, getting peptides to build up at tumor sites is often inefficient, and peptide vaccines can still trigger unwanted immune responses. For anti-aging use, there is little long-term safety evidence, and for many peptides, results seen in laboratory studies have not yet been confirmed in real-life trials [14,19,20]. In Bangladesh, limited resources make these challenges more prominently difficult to work with. Peptide research is often slowed by limited access to advanced synthesis tools, nanotechnology platforms, and specialized clinical research facilities. There is also a lack of staff with the right training and experience in peptide therapeutics and drug delivery systems. Regulatory rules for moving peptide-based treatments from the lab into clinical use are still limited, which slows approval and delays patient access.

Future directions and clinical outlooks

Future directions for this work focus on what should be tested next and why it matters. A clear next step is to repeat the study with a larger and more varied sample, then compare results across settings to see whether the same patterns hold. It would also help to track outcomes over a longer period, since short time frames can miss slow changes. Another practical step is to refine the measures used in the study, especially where key terms were broad or open to different readings. Finally, future research should spell out limits more clearly and link new questions to specific gaps found in the current findings. Peptide research will likely grow as nanotechnology, peptide engineering, and computational methods are brought together.

The stability and half-life of the biomolecules can be improved through chemical changes such as cyclization, substituting D-amino acids, and PEGylation [16,27]. Stimuli-responsive peptides can be designed to release drugs only under conditions found in the tumor microenvironment [16,17]. Personalized peptide vaccines and peptide-drug conjugates may improve target specificity while reducing unwanted side effects. Immunomodulatory peptides that target PD-1/PD-L1, CTLA-4, and TIGIT may strengthen antitumor immune responses and work alongside current therapies [17,19,21]. Machine learning methods such as PCA and k-means clustering can support the design of highly active peptides by identifying the physicochemical features most associated with activity [28]. In anti-aging research, senotherapeutic peptides such as Pep 14 are often treated as reference compounds when researchers design interventions aimed at specific organs.

Bioactive peptides in cancer: opportunities and future of peptide status in developing countries

Developing countries like Bangladesh has diverse biological resources like marine algae, fish, and plants as they can provide untapped potential for peptide discovery. Establishing national peptide research centers, GMP facilities, and peptide bioinformatics programs can accelerate translational research. Collaboration with global institutions and focus on low-cost, high-impact therapeutic peptides could establish Bangladesh as a regional hub for peptide innovation. In Bangladesh, cancer is now widely seen as a growing public health burden, while access to advanced treatments and newer medical technologies remains limited [26]. Peptide research in the country is still at an early point. Work moves slowly because there are few local labs that can synthesize peptides, importing materials is expensive, and there are not many clinical trials to test new findings in patients. A clearer view of what peptides do and how they might be applied could support the development of therapies that fit local needs and remain affordable [26].

In Bangladesh, the number of older adults is rising along with age-related illnesses, but peptide-based anti-aging treatments are still out of reach for most people because they cost too much and the country has limited local research capacity [19,26]. We still need local studies and clinical trials to check how well peptide interventions work and how safe they are for people in this group. Peptide therapies sit in an awkward middle space between small-molecule drugs and larger biologics. They can be very selective in what they bind to, which is a strength in theory, but in practice their physical and chemical limits often shape what is possible in the clinic.

As this research moves into human clinical studies, it will be important to include participants from Bangladesh, especially local communities, to check safety and how well the intervention works, and to see whether cultural practices or genetic differences shape the response. In Bangladesh, setting up local peptide-synthesis labs, building long-term partnerships with international research centers, and backing biotechnology policy measures could help produce affordable peptide therapies that match local health needs [16,26-28]. Running clinical trials in the country would generate data that reflect the local population (Figure 3). This kind of evidence is needed to judge how well an intervention works and how safe it is in that setting, so that results from research can be applied to patient care with more confidence.

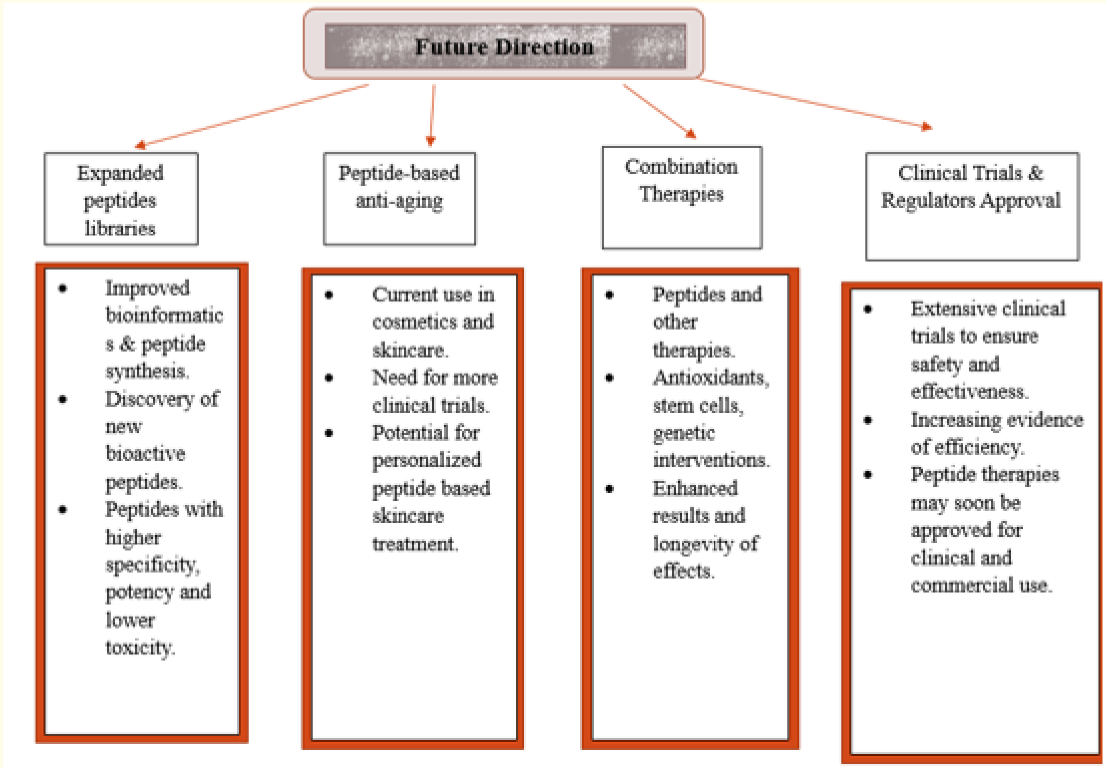

Figure 3: *Future directions in peptide-based research.*

The flowchart represents the possible directions in peptide anti-aging studies in the near future and its suggested directions. The illustration emphasizes the increase in peptide libraries with advanced bioinformatics and peptide synthesizing methods, the increasing applications of peptide therapeutic approaches in cosmetic and other self-care personalized products, a combination of peptide approaches with existing therapeutic methods for improved efficacy and long-term results, and a crucial role of extensive human clinical trials and approval in ensuring safety and efficacy of the therapeutic approach.

The manuscript describes the main challenges in peptide research and peptide-based status in Bangladesh and outlines practical next steps that could help address these barriers [2,10,17,24,28]. This study brings together what is known about natural, synthetic, and marine-derived peptides to give undergraduate students and early-stage researchers a clear overview of how peptides are being studied for medical and cosmetic uses [2-4,9,12,13,20,29]. Peptides are short chains of amino acids that can be designed to take part in many steps of cancer treatment [2-4,10,24]. In this setting, they are often studied because they can bind to targets on cancer cells with good selectivity [10,19,21-23,25,26]. That selectivity matters in therapy, since it may help direct a drug toward tumor tissue while limiting exposure to healthy cells [10,15,16].

Conclusion

To conclude, the evidence reviewed here supports the main claim that peptides are very useful and effective biomolecule especially in aging and other chronically diagnosed diseases like cancer. While there are limits in the process of it all and some open questions, the overall results are consistent and offer a useful base for future study. Peptides are being studied as potential treatments for cancer and as effective bio tools in research on age-related decline. They tend to act on well-defined targets, show relatively low toxicity, and work through more than one mechanism, which may help address major health problems. Peptides are studied in cancer treatment because they can home in on tumor tissue, shape immune responses, and carry drugs to the intended site and show a high rate of successful positive response. In on aging research, they are examined for their potential to slow cellular senescence, support DNA repair, and help maintain the health of a lot of biological functions. Even with their potential, several issues still need more work, such as stability, bioavailability, immunogenicity, and cost, and these limitations are especially hard to manage in resource-limited settings like Bangladesh. To address these barriers, research should focus on peptide engineering, nanotechnology-based delivery systems, computational design methods, and efforts to build local research and manufacturing capacity. Continued work on peptide-based drugs, paired with building local manufacturing and research capacity and running well-designed clinical trials, could move peptide treatments closer to routine care and will open new sustainable doors for healthier better quality of life. This could reduce costs and widen access to new options for cancer, age-related conditions, and other illnesses, both in Bangladesh and worldwide.

Authors' Contributions

TS- searched literatures, synchronized the data, wrote the initial draft of manuscript; AA- reviewed and edited the manuscript; MMA- conceived the idea, designed the total research plan, supervised the work, synchronized the data, wrote, and edited the final manuscript.

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Conflict of Interest

All Authors declare no conflict of interest.

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