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Peptides: The Universal Language of Life

Simply put, peptides are compounds formed by linking multiple amino acids through peptide bonds. They can be understood as biological macromolecules smaller than proteins. Typically composed of 10 to 50 amino acids, peptides serve as structural and functional fragments of proteins, playing multiple critical roles in living organisms as messengers, regulators, and builders. For instance, well-known examples like insulin (regulating blood sugar) and oxytocin (associated with childbirth and emotions) are classic peptide hormones. It is precisely due to the precise biological functions of peptides that scientists have begun synthesizing specific peptides artificially to serve human health and well-being.

How are peptides “built”?

Synthetic peptides are created by precisely linking amino acids one by one according to a specific blueprint. The most widely used method today is solid-phase peptide synthesis (SPPS), for which its inventor, Bruce Merrifield, was awarded the Nobel Prize in Chemistry in 1984. This method can be vividly imagined as stringing pearls (amino acids) onto a growing “pearl necklace”:

1. Anchor the starting point: Fix the first amino acid onto an insoluble solid resin bead.

2. Stepwise Extension: Subsequently, the second protected amino acid is introduced, activated, and linked to the first amino acid. The protecting group is then removed, exposing a new reaction site for the addition of the third amino acid... This process is repeated cyclically.

3. Final Release: Once the entire chain is synthesized, the peptide is chemically cleaved from the resin and all protecting groups are removed to yield the final product.

The primary advantage of this method lies in its automation potential, as intermediate products do not require cumbersome purification at each step. This significantly enhances synthesis efficiency, enabling rapid, large-scale peptide production. For longer peptide chains or complex proteins, genetic engineering methods are often employed, utilizing microorganisms (such as *E. coli*) or cells for “biosynthesis.”

Practical Applications of Peptide Synthesis: The capability of peptide synthesis has brought revolutionary changes to multiple fields. Below are some applications closely related to our daily lives:

Pharmaceutical Research and Development and Disease Treatment

Peptide drugs have become a hotspot in research and development due to their high specificity (like a precise key that unlocks only one lock) and low toxicity (relatively minor side effects). Beyond the classic insulin, peptide drugs are now widely used in cancer treatment (e.g., drugs targeting specific cancer cells), immune disorders (e.g., rheumatoid arthritis), metabolic diseases (e.g., diabetes), and antiviral therapies (e.g., HIV/AIDS). Globally, approximately 60-70 peptide drugs are currently on the market, with hundreds more in clinical trials, demonstrating immense development potential.

Vaccine Development

Peptide vaccines represent one of the hallmarks of third-generation vaccine technology. Scientists can artificially synthesize peptide fragments unique to viral or cancer cell surfaces as antigens. When injected into the human body, these train the immune system to precisely recognize and attack pathogens or diseased cells. This vaccine type offers high safety (containing no live pathogens) and relatively low production costs, demonstrating broad prospects in vaccine development for certain cancers and infectious diseases.

Biomedical Materials

Through design, peptides can self-assemble into specific structures such as hydrogels. These materials exhibit excellent biocompatibility and can be utilized in tissue engineering (e.g., repairing damaged bones or nerves) and drug delivery systems (precisely encapsulating and transporting drugs to target sites, enhancing efficacy while minimizing side effects).

Diagnostic Tools

Synthetic peptides serve as highly sensitive biomarkers for developing disease detection kits. For instance, peptide-based diagnostic reagents can specifically recognize antibodies associated with hepatitis, AIDS, certain cancers, and other diseases, thereby aiding early diagnosis and precision medicine.

Challenges and Future Outlook

Although peptide synthesis technology has reached a high level of maturity, it still faces certain challenges. For instance, the synthesis of long-chain peptides incurs relatively high costs, and peptide drugs are typically not suitable for oral administration (as they are easily degraded in the gastrointestinal tract and require injection for delivery).

Future development directions include:

Automation and Intelligence: More efficient automated synthesizers and AI-assisted design will further enhance synthesis efficiency and

success rates.

Novel Delivery Methods: Researchers are actively developing more convenient administration routes such as oral, nasal inhalation, and transdermal absorption.

Personalized Medicine: Tailoring peptide drugs or vaccines for specific patients based on individual genetic information.