

One Hundred Years of Peptide Chemistry

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Emil Fischer is considered to be the founding father of the field of peptide chemistry and originator of the term peptide. In the beginning of the 20th century, Fischer had a clear vision to foresee the day when a protein would be synthesized. Subsequent to this brilliant beginning, progress however was slow for the next 50 years. In 1953, the chemical synthesis of oxytocin by duVigneaud was a landmark achievement. The subsequent decades witnessed the discovery of a vast number of biologically active peptides. The last two decades of the 20th century was filled with hopes of multiple simultaneous synthesis, peptide libraries and peptide vaccines. This article is a concise account of the types of family of peptides discovered and their biological role.

Introduction

Box 1.

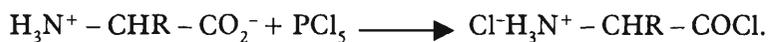


In 1902, Emil Fischer (1852-1919) was awarded the Nobel Prize in Chemistry, the second one after the institution of this award. van't Hoff received the first Nobel Prize in Chemistry in 1901.

In 1901, Emil Fischer (with E Fourneau) published an article which reports the preparation of the first dipeptide, glycylglycine, obtained by partial hydrolysis of the diketopiperazine of glycine in the laboratory. At the 14th meeting of the German scientists and physicians on September 22, 1902 at Karlsbad, Fischer introduced the name peptides (from pepsis = digestion or peptones = digestion products of proteins). The term 'peptides' denotes relatively small compounds which resemble proteins except that the latter are higher molecular weight substances. Thus, the molecules built up of 50 or more amino acids are generally regarded as proteins and those containing fewer number of residues are often denoted as peptides. The chemical synthesis of peptides, as envisaged by Fischer, involves the reproduction or perhaps recreation of Nature's molecules.

Five years later, in his famous lecture at the Deutsche Chemische Gesellschaft at Berlin, in January 1906, Fischer gave an illumi-

native review of his school of scientists and their efforts on peptide synthesis, which stimulated speculations on the imminent synthetic availability of living matter in the press. He eventually succeeded (with Axhausen) in synthesizing an impressive octadecapeptide, *L*-Leu-(Gly)₃-*L*-Leu-(Gly)₃-*L*-Leu-(Gly)₈-Gly. Due to the nonavailability of a method for removing the benzoyl or acetyl groups, Fischer employed the first urethane type protecting ethoxycarbonyl group (C₂H₅OCO) with a hope that it can be removed from the amino nitrogen by reaction with mild alkali. He was able to perform coupling at the carboxyl group, and to achieve this, he prepared amino acid chloride hydrochlorides.



Introduction of the amino protecting benzyloxycarbonyl group in 1932 by Max Bergmann and Leonidas Zervas coupled with improvements in the methods of peptide bond formation culminated into the chemical synthesis of the oligopeptide hormone oxytocin by du Vigneaud in 1953. The discovery of a method for sequencing of amino acids in polypeptides and proteins is an epoch making event in the history of peptide chemistry. From thereon, the synthesis of peptides progressed by leaps and bounds.

The demand for peptides and proteins is enormous, and increasing rapidly with time. During the past 35 years the discovery of a vast array of naturally occurring peptides with potent and specific biological activities has further increased their importance. Pharmacological studies required synthesis of not only the often hard-to-isolate natural peptides, but also of numerous analogs, which led to investigations on the chemical structure-biological activity relationship.

Amino Acids and Peptide Bond

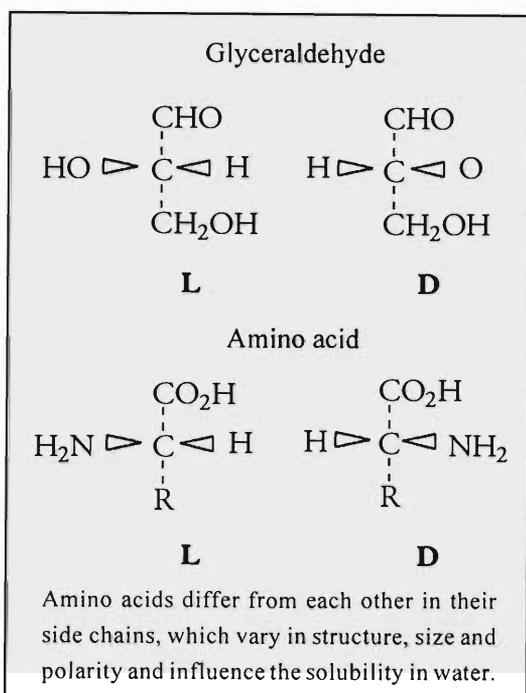
The monomers present as repeat units in peptides and proteins are α -amino acids (a carboxyl group and an amino group bounded to the same carbon atom, in the α -carbon). The α -carbon is asymmetric, bonded to four different substituent groups, and is

Box 2.

Many large peptides made by Fischer, may not meet today's criteria of purity! However, half a century later, 31 out of 34 peptides from Fischer's laboratory (made available by his son H O L Fischer) were found to be pure enough to give a single spot by paper chromatography.

Box 3.

Proteins (from the Greek *protos* = first or *proteios* = primary) are the most abundant biopolymers found in living cells. They are present not only in all cells but also in all components of cells. They occur in many varieties, thousands can be found in a single cell. They exhibit great diversity in biological function.



thus a chiral center. Today, 20 amino acids are known as genetically encoded as building blocks of peptides and proteins. Almost all of them present in peptides have *L*-configuration. *D*-amino acids have been found only in small peptides of bacterial cell walls, peptide antibiotics and peptides in South American frog skin.

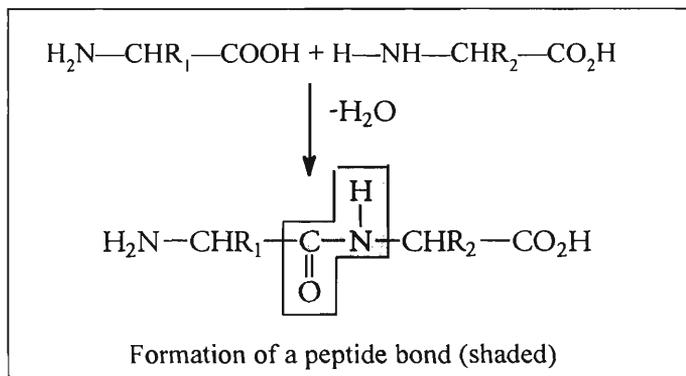
The condensation of two amino acid molecules through covalent linkage results in a dipeptide (amide bond). Such a linkage is formed by elimination of water from the α -carboxyl group of one amino acid and the α -amino group of another.

The polypeptide chain can be synthesized by successive addition of amino acids.

Peptides and Biological Activity

Hormones (derived from the Greek verb *horman*, meaning 'to stir up or excite') are chemical messengers secreted in one part of the body, carried rapidly in the blood and finally exert action on other parts of the body.

Biologically active peptides range in size from small molecules containing only two or three amino acids to large molecules containing several tens of amino acids. Among them, neuropeptides, hypothalamic hormones¹ (releasing and release-inhibiting hormones), proteohormones of the pituitary, thyroid hormones, gastrointestinal peptides, muramyl peptides, peptides of immunological significance, peptide vaccines, plasma kinins,



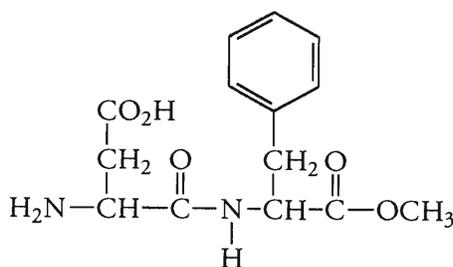
Box 4.

Fred Sanger of Cambridge University used 2,4-dinitrofluorobenzene as a marker for *N*-terminal amino acid of a peptide to elucidate the entire structure of insulin in 1955 employing partial peptide fragment sequences in the manner of jigsaw puzzles for which he was awarded the Nobel Prize in Chemistry in 1958. Unaffected by acclaim, he continued the work with uninterrupted zeal and made an in-depth study of nucleic acids and developed a method for DNA sequencing by the enzymatic method. Recognizing this contribution he became the recipient of the Nobel Prize in Chemistry again in 1980. Thus, Sanger is the only person to receive the Nobel Prize on two occasions in Chemistry.

atrial natriuretic peptides, peptide antibiotics, peptide toxins, peptide insecticides and herbicides are some of the important classes.

Peptide Hormones: Among the plethora of peptide hormones, peptides which are already in clinical use and a few others described in this section. Among the peptides present in the brain, thyrotropin releasing hormone (TRH) was the first to be isolated from 1,00,000 pig hypothalami. This is the molecule by which the hypothalamus through the pituitary regulates the functions of the thyroid gland. Later, the first isolation of 800 μg of luteinizing hormone releasing hormone (LHRH or gonadoliberin, pGlu-His-Trp-Ser-Tyr-Gly-Leu-Arg-Pro-Gly-NH₂) from ventral hypothalami of 1,65,000 pigs was achieved by 12 successive purification steps by Andrew V Schally and Roger Guillemin, who were awarded the Nobel Prize for Medicine and Physiology in 1977. LHRH acts on the pituitary to promote rapid release of LH and follicle-stimulating hormone (FSH), which in turn regulates ovulation and spermatogenesis. Among several of its clinical applications, LHRH and its analogs, find use as a nonsteroidal male and female contraceptive or as fertility agents. Somatostatin, the tetra-decapeptide hormone released by the hypothalamus,

Small peptides can have large biological effects



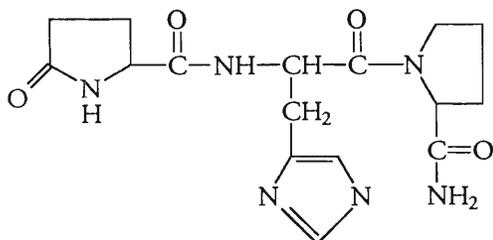
Artificial sweetener, commercially synthesized, known as Aspartame® or Nutrasweet®. It is about 200 times sweeter than sucrose and possesses a good flavour without unpleasant aftertaste. Its importance for weight watchers and diabetics is obvious.

Box 5.

Oxytocin, the first hormone to be isolated, structure determined and synthesized in the laboratory by Vincent du Vigneaud (Nobel Prize in Chemistry in 1955), is clinically used for the stimulation of uterine contraction in cases of labor. It also plays a pivotal role in milk-ejection in lactating glands.

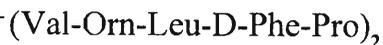
² There is no doubt regarding the exceptional significance of insulin in medicine. It controls the unfortunately rather common deficiency disease diabetes mellitus.

plays an important physiological role as an inhibitor for the release of several hormones (glucagon, growth hormone, insulin, gastrin). The octapeptide angiotension II (Asp-Arg-Val-Tyr-Ile-His-Pro-Phe) causes increase in blood pressure. α -melanocyte stimulating hormone (α -MSH) also called as α -melanotropin (Ac-Ser-Tyr-Ser-Met-Glu-His-Phe-Arg-Trp-Gly-Lys-Pro-Val-NH₂), is secreted in the anterior lobe of the pituitary gland. It exerts its activity at peripheral receptors, which are primarily responsible for its pigmentation properties. The other hormone secreted in the anterior lobe is a 39 residue peptide corticotrophin or adrenocorticotropin hormone (ACTH). This finds use in medicine for the treatment of hypophyseal insufficiencies and inflammatory processes. The gastrin family of peptides play a significant role in gastrointestinal functions including secretion, motility and absorption. Cholecystokinin is an important hormone, which belongs to this family mediating digestive functions and feeding behavior. In the course of the isolation of oxytocin, the second hormone of the pituitary, vasopressin, a peptide with pressor and antidiuretic effects, was also isolated. The deficiency of vasopressin causes diabetes insipidus². Persons affected by it have excessive excretion of water, which is controlled by applying a solution of the peptide in the form of nasal spray. The vital regulation of the level of Ca²⁺ ions in the blood is controlled by parathyroid hormones. These hormones raise the level of calcium concentration in blood by mobilizing calcium uptake from the bones. On the other hand, the thyroid hormone, calcitonin directs the flow of calcium ions in the opposite direction. Thus a constant level of calcium ions is maintained in the blood.



Primary structure of TRH (pGlu-His-Pro-NH₂)

Neuropeptides: There are about 50 neuropeptides whose molecular structures are known; many of them exist within closely related families of molecules. Several endogenous opioid peptides [endorphins, enkephalins, dynorphins, dermorphins, deltorphins, dermorphin gene associated peptide



Gramicidin S

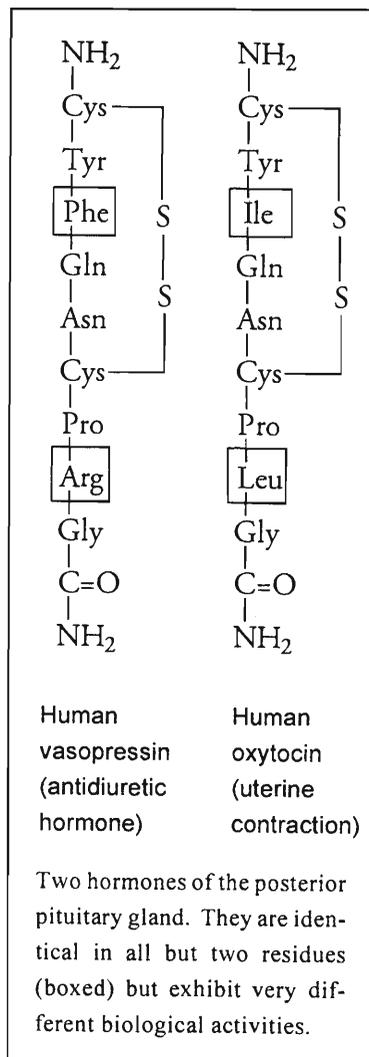
Active against gram-positive but not against gram-negative bacteria.

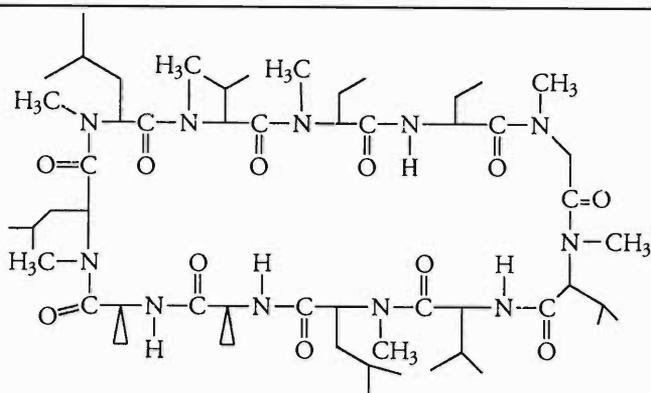
(DGAD)] possessing morphinomimetic properties are very well studied. Enkephalins (meaning isolated from the brain), two pentapeptides (Tyr-Gly-Gly-Phe-Met/Leu) are found in varying amounts in almost all regions of nervous system. A large number of their analogs have been synthesized to find out their role in pain transmission, since they act as transmitters of the pain-inhibitory neurons on the spinal cord. These brain morphins have been well studied which is known to allow analgesia to be separated from the development of addiction and dependence.

Peptide Leukotrienes: The peptide leukotrienes cause contraction of the bronchial smooth muscle and probably play an important role as mediators in allergic reactions (eg. asthma) and inflammations.

Peptide Antibiotics: The peptidic nature of penicillins has long been recognised. Penicillins and cephalosporins inhibit final stages of the enzymatic construction of the bacterial peptidoglycan cell wall component, a network of peptides and polysaccharides. The depsipeptide, valinomycin has been found to be active against a number of bacteria, yeasts and fungi.

Peptides of Immunological Significance: Immune responses to synthetic peptides constitute another important field of study. Serums raised against synthetic peptides are highly specific reagents for the corresponding native proteins from which the peptide amino acid sequence was derived. These antipeptide serums are powerful reagents for the detection and characterization of proteins.





Cyclosporin A, the potent immunosuppressant is currently used for preventing rejection of transplanted human organs. Its trade names are Sandimmune and Neoral®.

Poisonous Peptides: The most important component of snake venoms are polypeptide neurotoxins such as cobrotoxin, which produce lethal flaccid paralysis through a neuromuscle block. The peptides of amanita mushrooms such as antamanides are among the best known peptide poisons. The smallest dose of 50 μg can kill a 20 gm mouse within a few hours. (2.5 mg per kg of body weight). A search for inhibitors or antidotes through antagonists can be predicated.

Others: Actinomycin belongs to a class of chromopeptides and is characterized by its cytostatic growth inhibition in tumors and for antibacterial action. The cyclic desipeptides, destruxins act as insecticides whereas bialaphos (phosphinotricylalanyl alanine) has a strong herbicidal action. Peptides can be either sweet or bitter. The bitter peptide Arg-Gly-Pro-Pro-Ile-Val, isolated from casein hydrolysates and delicious tasting peptides from fish proteins has gained practical importance in the food industry. Nisin, produced by *Streptococcus lactis* is used as a food preservative. The atrial natriuretic peptides have diuretic properties. The phosphopeptide, (S)-alanyl-(R)-1-aminoethyl-phosphoric acid (alafosfalin) is effective against both gram positive and gram negative microorganisms. Albomycins are nucleopeptides which possess iron-complexing properties. Several muramyl peptides (glycopeptides) have the possibility of being used as adjuvants in combination with vaccines or with antibiotics.

Box 6.

What of the future? There will be a fusion of the biotechnological and chemical synthetic approaches to peptide and protein manufacture resulting in synthetic peptide vaccines part of everyday life.

Concluding Remarks

The overwhelming and ever increasing body of knowledge in this area clearly shows that the variety of peptides synthesized or

isolated from natural sources are of tremendous significance. Due to the denaturation and enzymatic degradation of peptide substances in the gastrointestinal tract, at present, they find clinical use as parenteral, sublingual or intranasal administration. The predominant clinical use of peptide pharmaceuticals and their applications in diagnostics have shown significant potential use within its narrow limits. Introduction of wide range of active peptide substances in pharmacotherapy will have to wait to foresee the development of peptide drugs that are administered orally.

Presenting this material in a few pages needed an acrobatic effort in abstractions by the author; the reader is therefore requested to refer to the Suggested Reading and references cited therein for more detailed information on each and every class of peptides and their significance.

Acknowledgements

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Suggested Reading

- [1] E Schroder and K Lubke, *The Peptides* (in two volumes: Vol. 1 - Methods of peptide synthesis; Vol. 2 Synthesis, occurrence and action of biologically active peptides), Academic Press, London, 1965.
- [2] M Bodanszky, *Principles of Peptide Synthesis*, Springer-Verlag, Berlin, 1984.
- [3] M Bodanszky, *Peptide Chemistry: A Practical Textbook*, Springer-Verlag, Berlin, 1988.
- [4] T Wieland and M Bodanszky, *The World of Peptides: A Brief History of Peptide Chemistry*, Springer-Verlag, Berlin, 1991.
- [5] J Jones, *The Chemical Synthesis of Peptides*, Clarendon Press, Oxford, 1991.
- [6] B Gutte, *Peptides: Synthesis, Structures and Applications*, Academic Press, San Diego, 1995.

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