

Coenzymes in the Evolution of Life

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Received: January 06, 2021; **Accepted:** January 18, 2021; **Published:** January 26, 2021

Abstract

The evolution of coenzymes, as well as their impact on the beginning of life, is crucial to comprehending our existence. After establishing reasonable hypotheses about the emergence of prebiotic chemical building blocks, which were most likely created under palaeogeochemical conditions, and assuming that these smaller compounds must have become integrated to afford complex macromolecules like RNA, the question of coenzyme origin and its relationship to the evolution of functional biochemistry should gain renewed vigor. Many coenzymes have a basic chemical structure and are commonly produced from nucleotides, implying that they coexisted with the emergence of RNA and may have played a key role in early metabolism. This review presents possible possibilities on the primordial creation of essential elements inside chosen existing coenzymes, based on current prebiotic evolution theories that aim to explain the development of favored biological building blocks. Coenzymes may have drastically enlarged early protometabolic networks and the catalytic scope of RNA during the emergence of life by combining with primordial RNA.

Keywords: Protein structures; Prebiotic metabolism; RNA synthesis; Molecular evolution

Introduction

When we believe that existing life still bears the imprint of its beginning and that ancestral conceptions can be extracted from the realm of extant mechanism, studying the origin of life becomes tangibly relevant to our own experience. The origin of nucleotides and proteins is now linked, but the evolution of coenzymes has received little attention. This is remarkable because coenzymes, such as pyridoxal phosphate (PLP, 1), are normally tiny and simple organic non-protein chemicals that bind to enzyme macromolecules and participate in catalytic biotransformations. It has been demonstrated that without a coenzyme partner, protein structures (apoenzymes) are inactive and that this relationship is synergistic in many circumstances. In a biological setting, this alliance promotes site-specific oxidation and reduction, as well as group transfer reactions such as acylation, phosphorylation, methylation, and formal acyl-anion transfer, many of which are not influenced by enzymes based only on a protein scaffold. As a result, coenzymes must have played a crucial role in the formation of sophisticated metabolic networks at some point during the evolution of life. Coenzymes may have originated in an early primitive prebiotic metabolism, long before enzymes or other polymers were discovered, and before molecular replication was invented. This early metabolism could have self-propagated by autocatalytic routes and cycles, which would have required a steady supply of organic building blocks, including those with coenzyme-like capabilities. Several small-molecule metabolic cycles have already been proposed as possible prebiotic mechanisms in this area. Assuming this idea, however, entails speculating on a protometabolism of tiny coenzyme-like molecules for which there are few traces or evidence today. Coenzymes, in general, have weak catalytic capabilities when compared to coenzyme-enzyme complexes, and it's plausible to suppose that this is also true for their role in a primitive metabolic network. With the emergence of macromolecular templates, their full potential must have been fulfilled, resulting in coenzyme-like molecules with catalytic characteristics and/or the ability to stimulate a higher range of chemical transformations. If such an association emerged at the same time as RNA macromolecules, the coenzymes, or early simpler analogs, could have acted as "holoribozymes" (in analogy to the term holoenzyme) by binding to nucleic acid fragments either through electrostatic or hydrogen-bonding interactions or through covalent linkage to the RNA terminus via a phosphate ester. Indeed, for the nucleotide-derived coenzymes nicotinamide adenine dinucleotide, riboflavin, and S-adenosylmethionine, the latter approach has been considered. In a larger sense, it's possible that the interaction or templating of nucleotide bases with primitive coenzyme-like molecules supported and catalyzed the initial RNA syntheses in and of it. Single amino acids would eventually become linked to catalytic RNA templates, allowing them to condense and form the first peptide structures. The coupling of these novel peptides with

RNA is thought to have increased the diversity and complexity of chemical reactions by expanding the pool of catalytic macromolecular binding sites. As molecular evolution advanced, protein structures began to supplant nucleic acid subunits, resulting in enzymes that retain the catalytic core of their active sites, including those linked to today's coenzymes. Further molecular evolution would have resulted in enormous families of homologous enzymes capable of self-regulating biochemical networks. This nucleotide/amino acid replacement scenario is more feasible than the opposite, given the expected advantages of proteins over RNA as catalysts, such as chemical stability and structural diversity of the available monomeric units. Alternatively, it's plausible that coenzymes had a role in the evolution of peptides, later on, directly widening the catalytic scope of protein-based biotransformation and merely acting as bystanders in the hypothetical RNA world. One of the few extremely speculative and hypothesis-driven scientific endeavors in which chemists have and must play a significant role in deciphering the evolution of life. The Miller Urey spark discharge experiment¹³ is an excellent example of how chemical sciences can make a significant contribution to solving a basic scientific puzzle. Under severely reducing conditions and with an electric spark, the experiment proved that amino acids and lower carboxylic/fatty acids can all be made from four components: methane, ammonia, diatomic hydrogen, and carbon monoxide. By predicting how protometabolic networks would have arisen from principal building components that are supposed to have formed under primordial settings, chemists were able to “reinvent” the molecular basis for the genesis of life. These hypotheses were not only created as pure theories based on speculation; they were also backed up by new experimental findings. Even though coenzymes are chemical entities that execute transformations via different methods, they have largely escaped our current understanding of abiogenesis, or the origin of life.

Conclusion

Coenzyme-like compounds might have formed in primordial settings and examine their potential roles in the evolution of primitive metabolism. I look at how the presence of coenzymes in a prebiotic and pre-RNA environment might fit in with or add to existing chemical abiogenesis theories. In addition, the first review existing prebiotic chemistry theories and concepts, particularly those that describe the origin of favored organic building blocks and early protometabolic networks. The potential for these primitive components to have contributed to the assembly of prebiotic coenzymes is then critically assessed, using current biosynthesis mechanisms and technological trends as a guide. It is my objective to suggest new research avenues linked to prebiotic chemistry and the genesis of life throughout this conversation, as well as to advocate for future attempts to better understand the historical significance of coenzyme molecules through modern testing. It's worth noting at this point that prebiotic simulation experiments should be compatible with the geochemical conditions that occurred on early Earth.