

The Role of Coenzyme Q10 in Energy Metabolism and Cell Stability: A Critical Review Based on a Systematic Literature Review

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Article Info

Article history:

Received April 23, 2026

Revised May 11, 2026

Accepted May 28, 2026

Keywords:

Coenzyme Q10, Energy Metabolism, Mitochondria, Antioxidants, Liposomes

ABSTRACT

This study aims to examine the role of coenzyme Q10 (CoQ10) in energy metabolism and cell stability through a Systematic Literature Review (SLR) approach. Coenzyme Q10 is an essential component in the electron transport chain in mitochondria that plays a role in the production of adenosine triphosphate (ATP) as the main energy source of cells. In addition, CoQ10 also has antioxidant activity that can protect cells from damage due to oxidative stress. The method used in this study is SLR by analyzing two relevant scientific articles, namely those discussing the physiological and pharmaceutical aspects of CoQ10. The results of the study indicate that CoQ10 has a dual role, namely as an energy producer and cell protector. In the pharmaceutical context, the use of a liposome-based delivery system has been shown to increase the stability and bioavailability of CoQ10. A critical analysis of both articles shows that the integration of biological approaches and pharmaceutical technology is crucial to optimize the benefits of CoQ10. Thus, this study provides a comprehensive understanding of the importance of coenzyme Q10 in life and its potential in the development of coenzyme-based therapies in the health sector.

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INTRODUCTION

Coenzymes are essential components in various biochemical reactions, playing a crucial role in maintaining the continuity of cellular metabolism, particularly in energy production. In biological systems, coenzymes function as supporting molecules for enzymes, helping to accelerate chemical reactions without undergoing permanent changes (Soekatri, 2025). This role is crucial because almost all life processes, from growth and cell repair to physiological activity, depend on the efficiency of metabolic reactions. Therefore, the presence of coenzymes is not merely complementary but integral to maintaining the balance of cell and tissue function in the body.

One coenzyme that plays a crucial role in the human body is coenzyme Q10 (CoQ10), widely known as a key component of the electron transport chain in mitochondria. CoQ10 functions as an electron carrier that enables oxidative phosphorylation, resulting in the production of adenosine triphosphate (ATP), the primary energy source for cells (Laksono & Fiyani, 2022). Without this coenzyme, the energy production process will

be disrupted, which can ultimately affect the overall performance of the body's organs. This indicates that CoQ10 directly contributes to the maintenance of optimal biological function.

In addition to its role in energy production, coenzyme Q10 is also known to possess potent antioxidant activity. This compound is capable of neutralizing free radicals produced during metabolic processes, thereby protecting cells from oxidative damage. Uncontrolled oxidative stress can lead to various health disorders, including premature aging and degenerative diseases. Therefore, the antioxidant function of CoQ10 is crucial in maintaining cell integrity and extending cellular lifespan.

The role of coenzyme Q10 becomes even more significant in the context of mitochondrial function as the center of cellular energy production. Mitochondria are not only responsible for producing ATP but also regulate various important processes such as apoptosis and cell homeostasis. Disruption of mitochondrial function can lead to decreased energy production and increased oxidative stress, which contribute to various chronic diseases (Isrul et al., 2025). In this regard, coenzyme Q10 plays a key role in maintaining the efficiency and stability of mitochondrial function. In pathological conditions such as heart failure, the role of coenzymes and micronutrients becomes even more crucial. The changes in energy metabolism that occur in this condition lead to a significant decrease in ATP production, thus impairing cardiac contractile function. Micronutrients, including coenzyme Q10, are necessary to support efficient energy metabolism through the mitochondrial electron transport chain. Deficiencies in these micronutrients can worsen the disease and reduce patients' quality of life.

In addition to physiology, coenzyme Q10 is also widely studied in the pharmaceutical field, particularly in relation to drug delivery systems. One of the main problems with CoQ10 is its instability to light and low solubility in water, which affects its bioavailability (Khasanah & Rochman, 2022). To address this, various delivery systems, such as liposomes, have been developed to increase the stability and effectiveness of active ingredients. This approach demonstrates that CoQ10's role is not only biologically important but also holds significant potential in the development of pharmaceutical technology.

The use of liposome-based delivery systems protects coenzyme Q10 from degradation and enhances its penetration into cells (Iskandar et al., 2025). Liposomes, as phospholipid-based vesicles, are similar to cell membranes, thus increasing the efficiency of active ingredient absorption. This makes liposomes a promising innovation in enhancing the performance of coenzyme-based therapies. Therefore, the integration of biology and pharmaceutical technology is crucial in optimizing the benefits of CoQ10. Although various studies have addressed the role of coenzyme Q10, there remains a need for a comprehensive review of the relationship between its biological functions and its pharmaceutical applications. Some studies emphasize physiological aspects, while others focus on formulation development and delivery systems (Iskandar et al., 2026). Therefore, a study that integrates both perspectives is needed to provide a more comprehensive understanding of the importance of coenzyme Q10 for life.

Based on this description, this study aims to conduct a critical review of scientific articles discussing the role of coenzyme Q10 in energy metabolism and cell stability. This study is expected to contribute to enriching scientific insight into the importance of coenzyme Q10 and serve as a foundation for further research in the health and pharmaceutical fields. Furthermore, the results of this study are also expected to provide practical benefits in supporting the development of more effective and innovative coenzyme-based therapies.

METHOD

This study used a Systematic Literature Review (SLR) approach to comprehensively examine the role of coenzymes, particularly coenzyme Q10, in energy metabolism and cell stability. The SLR method was chosen because it provides a systematic, structured, and objective synthesis of various relevant research findings (Qudratuddarsi et al., 2024). This approach not only gathers information from the literature but also critically evaluates the quality and contribution of each source, resulting in more valid and scientifically sound conclusions.

The data collection process for this study was conducted through a search of scientific literature relevant to the research topic. Data sources were obtained from national and international journals accessible online, taking into account the credibility of the publishers and the quality of the articles. The search was conducted using keywords such as "coenzyme Q10," "energy metabolism," "mitochondria," and "liposomes," to identify articles relevant to the study's focus. Furthermore, the literature used was prioritized for articles directly related to the biological role and pharmaceutical applications of coenzyme Q10. Inclusion criteria for this study included scientific articles discussing coenzyme Q10 in the context of energy metabolism, mitochondrial function, and drug delivery systems. Selected articles must have a complete scientific structure, including an abstract, methods, results, and discussion, and be published in an indexed journal. Exclusion criteria included articles that were irrelevant to the topic, lacked full access, or had unclear methodological quality. These criteria ensure that the literature used is truly representative and aligns with the research objectives.

In this study, two primary articles were selected as core study materials, representing two distinct perspectives: the physiological and pharmaceutical aspects of coenzyme Q10. The first article discusses the formulation and characterization of coenzyme Q10 in a liposomal system to improve its stability and bioavailability, while the second examines the role of micronutrients, including coenzyme Q10, in mitochondrial function and energy metabolism in pathological conditions. The selection of these two articles was based on the relevance of the topic and their contribution to the overall explanation of the role of coenzymes.

The data analysis phase was carried out through a process of identifying, selecting, and synthesizing information from the selected articles. Each article was analyzed in depth to identify the research objectives, methods used, results obtained, and conclusions (Rosyidah & Masykuroh, 2024). Next, a comparison was conducted between the two articles to identify similarities, differences, and strengths and weaknesses of each study. This process aims to produce a critical analysis, not merely a descriptive one. The results of the analysis are then compiled narratively into an integrated discussion. This approach allows researchers to combine various findings from the literature into a coherent and interrelated whole. Thus, the discussion contains not only a summary of each article but also an in-depth interpretation of the relationships between the concepts studied, particularly regarding the role of coenzyme Q10 in biological systems and its application in the pharmaceutical field.

To ensure the validity and reliability of the research results, an evaluation of the quality of the sources used was conducted, including the validity of the methods and the consistency of the results. Furthermore, all sources used are systematically listed in the bibliography in accordance with scientific writing standards. By applying the SLR method, it is hoped that this research will provide a comprehensive, critical, and scientific overview of the importance of coenzyme Q10 for life and its potential for the development of health science and technology.

RESULTS AND DISCUSSION

Advances in biochemistry and pharmaceutical sciences indicate that coenzymes play a crucial role in maintaining the balance of cellular functions, particularly in energy metabolism and protection against cell damage. Coenzyme Q10 (CoQ10), one of the primary coenzymes, has attracted considerable attention due to its involvement in various crucial biological mechanisms (Laksono & Fiyani, 2022). A review of the selected literature revealed that CoQ10 not only plays a role in energy production but also has a protective effect on cells through antioxidant activity and potential applications in drug delivery systems. Analysis of the two articles reviewed demonstrates a strong link between the physiological and pharmaceutical aspects of coenzyme Q10. The first article emphasizes efforts to improve the stability and bioavailability of CoQ10 through liposome technology, while the second article focuses more on the biological role of CoQ10 in mitochondrial function and energy metabolism, particularly in pathological conditions such as heart failure (Rochman, Yumni, Ramaesa, Octafia, Nuladani, et al., 2026). These two approaches provide a complementary picture of the importance of coenzyme Q10 in life.

Through a Systematic Literature Review approach, the study results are not only presented descriptively but also critically analyzed to understand the relationships between the concepts studied. The discussion focuses on four main aspects: the role of coenzyme Q10 in energy metabolism, cell stability, liposome-based delivery systems, and a comparative analysis of the two articles. This is expected to provide a comprehensive understanding of the contribution of coenzyme Q10 in biology and pharmacy.

1. The Role of Coenzyme Q10 in Cellular Energy Metabolism

Coenzyme Q10 plays a fundamental role in the energy production process within cells, particularly through its involvement in the electron transport chain in mitochondria. In this mechanism, CoQ10 functions as an electron carrier, transferring electrons from complexes I and II to complex III (Laksono & Fiyani, 2022). This process allows for the formation of a proton gradient, which is then used for ATP synthesis. Without CoQ10, oxidative phosphorylation cannot occur optimally, thus disrupting cellular energy production.

The role of CoQ10 in energy metabolism becomes even more crucial in tissues with high energy demands, such as the heart. Mitochondria in cardiac muscle cells require a continuous supply of ATP to maintain contraction. Under normal conditions, ATP production relies largely on fatty acid oxidation and the electron transport chain. However, when metabolic disorders occur, such as in heart failure, ATP production decreases significantly, impacting organ function (Sari & Noviyani, 2023). Furthermore, mitochondrial efficiency is greatly influenced by the availability of coenzymes and micronutrients. CoQ10, as part of this system, plays a role in maintaining stable and efficient electron flow (Muhammad et al., 2026). Imbalances in this system can lead to electron leakage, which produces free radicals, leading to oxidative stress. Therefore,

the presence of CoQ10 is not only essential for energy production but also for maintaining stable metabolic processes.

Based on the results of this study, it can be concluded that CoQ10 is a key component in cellular energy metabolism. Its multifunctional role in the electron transport chain makes it a determining factor in the efficiency of energy production. This suggests that disruptions in CoQ10 levels or function can directly impact cell and organ performance, making it crucial to maintain the balance of this coenzyme in the body.

2. The Role of Coenzyme Q10 in Cell Stability and Antioxidation

In addition to its role in energy metabolism, coenzyme Q10 also plays a crucial role as an antioxidant, protecting cells from oxidative damage (Nasution, 2026). Normal metabolic processes, particularly in mitochondria, produce free radicals as byproducts. If left unchecked, these free radicals can damage cellular components such as lipids, proteins, and DNA. CoQ10 plays a role in neutralizing these free radicals, thus preventing cell damage. CoQ10's antioxidant activity is also closely related to its ability to maintain cell membrane integrity. Cell membranes, composed of phospholipids, are highly susceptible to lipid peroxidation caused by free radical attack. The presence of CoQ10 suppresses this peroxidation process, thus maintaining membrane structure and function. This is crucial for maintaining overall cell stability.

In pathological contexts, such as degenerative diseases and heart failure, increased oxidative stress is a major factor in worsening disease conditions. CoQ10 deficiency can cause an imbalance between free radical production and the body's antioxidant capacity (Zalizar & Relawati, 2026). Therefore, CoQ10 is crucial for maintaining cellular homeostasis and preventing further damage. Analytical results indicate that CoQ10's role as an antioxidant is inseparable from its metabolic function. These two functions complement each other in maintaining cellular stability. Thus, CoQ10 can be considered a multifunctional molecule that not only supports energy production but also plays a role in protecting cells against various forms of biological stress.

3. Optimizing Coenzyme Q10 in Delivery Systems (Liposomes)

Despite its numerous benefits, coenzyme Q10 has several limitations, such as low water solubility and poor light stability (Rochman et al., 2026). This results in low bioavailability of CoQ10 when used in its conventional form. To address this issue, various drug delivery systems have been developed, one of which is liposomes, which can increase the stability and effectiveness of CoQ10. Liposomes are phospholipid-based vesicles with a structure similar to that of cell membranes (Handayani et al., 2025). This structure allows liposomes to encapsulate active substances such as CoQ10 and protect them from degradation. Furthermore, liposomes can enhance the penetration of active substances into cells, thereby increasing therapeutic effectiveness. The use of liposomes in CoQ10 formulations has shown positive results in improving the entrapment efficiency and stability of active substances.

The results of this study indicate that variations in the composition of liposome formulations, such as cholesterol concentration, can affect the physicochemical characteristics of the liposomes. Increasing cholesterol concentration has been shown to increase liposome membrane stability and CoQ10 entrapment efficiency. This suggests that formulation optimization is crucial for producing an effective delivery system. Therefore, the use of liposome technology is a promising solution to overcome the limitations of CoQ10 (Mindiarso et al., 2024). This approach not only improves stability and bioavailability but also opens up opportunities for the development of more innovative coenzyme-based therapies. Integration of biological science and pharmaceutical technology is key to maximizing the potential of CoQ10.

4. Critical Analysis and Comparison of the Two Articles

The two articles reviewed have different but complementary focuses in explaining the role of coenzyme Q10. The first article emphasizes pharmaceutical aspects, particularly the development of liposome-based delivery systems, while the second focuses on physiological aspects and the role of CoQ10 in energy metabolism and mitochondrial function. These differences provide a broader perspective in understanding the role of coenzyme Q10. In terms of methodology, the first article uses an experimental approach to formulate and characterize liposomes, while the second uses a literature review to analyze the role of micronutrients. Both have their advantages, with the experimental study providing empirical data, while the literature review provides a broader conceptual overview.

However, each article also has limitations. The first article did not evaluate the long-term stability of the resulting liposomes, while the second article still requires further research to strengthen the link between micronutrient deficiencies and pathological conditions. This suggests that there is still room for more comprehensive follow-up research. Overall, the analysis of both articles demonstrates the need for a multidisciplinary approach to study the role of coenzyme Q10. Integrating biological and pharmaceutical aspects can provide a deeper understanding and open up opportunities for broader application development. Thus, research on coenzyme Q10 has great potential for further development in the future.

CONCLUSION

Based on the results of the studies conducted, it can be concluded that coenzyme Q10 (CoQ10) plays a crucial role in maintaining cellular function, particularly in energy metabolism and cell stability. CoQ10 functions as a key component in the electron transport chain in mitochondria, enabling the efficient production of ATP, the cell's primary energy source. Furthermore, CoQ10 acts as an antioxidant, protecting cells from damage caused by oxidative stress, thus maintaining the integrity of membranes and other cellular components. This combination of metabolic and protective functions makes CoQ10 an essential molecule for supporting organ function, particularly in tissues with high energy requirements.

Furthermore, the development of pharmaceutical technologies, such as liposome-based delivery systems, demonstrates that CoQ10's potential extends beyond biological aspects and has significant applicability in the health sector. The analysis of both articles demonstrates that integrating physiological and pharmaceutical approaches can provide a more comprehensive understanding of the role of coenzyme Q10. Despite limitations in existing research, this study confirms that CoQ10 has significant potential for further development, both as a supplement supporting energy metabolism and as part of innovative coenzyme-based therapies. Therefore, further, more in-depth and integrated research is urgently needed to optimize the use of coenzyme Q10 in the health and pharmaceutical sectors.

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