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Opinion Article

Innovations in Chiral Separation using Capillary Electrophoresis

Andrew Lius*

Department of Chemistry, University of Toronto, Toronto, Canada

DESCRIPTION

Chirality is a fundamental property of many molecules, particularly in the field of pharmaceuticals, where the efficacy and safety of drugs can significantly differ between enantiomers. As a result, the separation of chiral compounds has become a important aspect of analytical chemistry. Traditional methods for chiral separation, such as High-Performance Liquid Chromatography (HPLC), have long been employed; however, they often face limitations regarding speed, efficiency, and resolution. Capillary Electrophoresis (CE) has emerged as a powerful alternative, offering distinct advantages in chiral separation due to its high efficiency, minimal sample volume requirements, and rapid analysis times. Recent innovations in CE technology and methodologies have further enhanced its application for chiral separations, making it an increasingly popular choice for researchers and analysts in various fields. Capillary electrophoresis is based on the differential migration of charged species in an electric field within a narrow capillary tube filled with an electrolyte solution. The separation occurs primarily due to differences in charge-to-size ratios of analytes, leading to varied velocities as they migrate towards the electrode of opposite charge. When applied to chiral separations, CE can utilize various chiral selectors (such as cyclodextrins, chiral surfactants, or polymeric additives) to enhance the resolution between enantiomers. Chiral selectors interact with the enantiomers through non-covalent interactions such as hydrogen bonding, hydrophobic interactions, and ionic interactions, resulting in differential migration rates. By optimizing the choice of chiral selectors and the separation conditions, researchers can achieve high-resolution separations of enantiomers in a variety of complex samples. Innovations in the design and synthesis of chiral selectors have expanded the range of available options for enhancing enantiomer separation. New chiral selectors, including modified cyclodextrins and synthetic polymers, have been developed to provide increased selectivity and sensitivity. These selectors often demonstrate improved solubility and stability, allowing for more effective interactions with a wider variety of analytes. The integration of microfluidic technology with CE has resulted in miniaturized separation systems that require significantly lower sample volumes and reagents. This innovation enables high-throughput analysis and real-time monitoring, making it particularly advantageous for applications in drug development and biomarker discovery. Microfluidic CE systems can be designed to include multiple detection methods, such as fluorescence and mass spectrometry, providing enhanced analytical capabilities.

Recent studies have highlighted the importance of temperature in influencing the separation of chiral compounds. Innovations in temperature-controlled CE systems allow for the optimization of separation conditions to enhance resolution. By precisely controlling the temperature during the separation process, researchers can improve the interaction kinetics between chiral selectors and analytes, leading to enhanced separation efficiency. Advances in injection techniques, such as electrokinetic and hydrodynamic methods, have improved the reproducibility and precision of chiral separations. Electrokinetic injection utilizes the electric field to control the amount of sample introduced into the capillary, allowing for consistent and accurate loading of analytes. This innovation minimizes sample loss and enhances detection sensitivity, particularly for trace-level analytes. The implementation of dual or multiple detection systems in CE has further enhanced the ability to analyze chiral compounds. Combining different detection methods, such as UV-visible, fluorescence, and mass spectrometry, enables researchers to obtain complementary information about the analytes, including structural characterization and quantitative analysis. Chiral CE has gained popularity in the pharmaceutical industry for analyzing the enantiomeric purity of drugs. Many chiral drugs exhibit different pharmacological effects based on their enantiomeric form; thus, precise separation and quantification are essential for ensuring drug safety and efficacy. CE's rapid analysis times and minimal sample requirements make it ideal for high-throughput screening in drug development. In the food industry, chiral separations are essential for detecting and quantifying chiral pesticides, flavors, and additives. CE has been used to assess the enantiomeric ratios of food components, contributing to quality control and regulatory compliance.

Correspondence to: Andrew Lius, Department of Chemistry, University of Toronto, Toronto, Canada, E-mail: andrewlius@jpeerres.com

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CONCLUSION

Innovations in chiral separation using capillary electrophoresis have significantly advanced the field of analytical chemistry, offering efficient, rapid, and sensitive methods for resolving enantiomers. The development of new chiral selectors, the integration of microfluidic technologies, and the implementation of advanced detection techniques have all contributed to the growing popularity of CE for chiral separations across various industries. As the demand for accurate and precise analytical methods continues to rise, chiral CE is poised to play a pivotal role in drug development, food safety, environmental monitoring, and biotechnology. The ongoing research and development efforts in this area will further enhance the capabilities of chiral CE, ensuring its relevance and applicability in addressing the challenges of complex chiral separations in the future.