Opinion
Volume 17:01, 2025

Journal of Bioanalysis & Biomedicine

ISSN: 1948-593X

Open Access

Application of Capillary Electrophoresis in Monitoring Protein Drug Stability

John Mwangi*

Department of Informatics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Torun, Poland

Introduction

Protein-based therapeutics, including monoclonal antibodies, enzymes, hormones, and fusion proteins, have become integral to modern medicine, offering high specificity and efficacy in treating complex diseases such as cancer, autoimmune disorders, and metabolic conditions. However, their structural complexity and sensitivity to environmental conditions present significant challenges in formulation, storage, and transportation. Protein stability is a critical quality attribute that directly impacts a drug's efficacy, immunogenicity, and shelf life. Conventional analytical methods such as High-Performance Liquid Chromatography (HPLC), gel electrophoresis, and mass spectrometry have been widely used for protein characterization, but they may fall short in resolving minor structural variants or degradation products. Capillary Electrophoresis (CE), owing to its high resolution, speed, low sample volume requirement, and ability to differentiate protein isoforms and aggregates, has emerged as a powerful tool in monitoring protein drug stability. This paper explores the applications of CE in evaluating stability-related changes in protein drugs under various stress conditions, highlighting its potential in both research and regulatory environments [1].

Description

Capillary electrophoresis is an electrophoretic separation technique that relies on the differential migration of charged molecules in an electric field through a narrow capillary filled with buffer solution. Various CE modes such as capillary zone electrophoresis (CZE), Capillary Isoelectric Focusing (CIEF), Capillary Gel Electrophoresis (CGE), and micellar electrokinetic chromatography (MEKC)—enable detailed analysis of protein charge heterogeneity, aggregation, glycosylation, and structural integrity. These features make CE particularly valuable for detecting subtle degradation or modification events, such as deamidation, oxidation, or fragmentation, which often occur during storage, transportation, or under accelerated stability testing.

To assess the utility of CE in protein stability monitoring, a case study was conducted on a recombinant monoclonal antibody subjected to thermal, pH, and oxidative stress conditions. Samples were collected at defined intervals and analyzed using CZE and CIEF to detect charge variants, while CGE was employed to quantify size-based changes, such as fragmentation and aggregation. The results indicated a gradual increase in acidic isoforms and low-molecular-weight fragments under elevated temperature and oxidative environments, revealing early-stage degradation. In contrast, pH stress induced basic variants due to lysine clipping and C-terminal amidation. These observations were critical in identifying degradation pathways and guiding the optimization of formulation buffers and storage parameters.

One of the distinct advantages of CE over traditional methods is its ability to resolve charge heterogeneity with greater precision and speed. CIEF, in particular, allows precise determination of the isoelectric point (pI) of protein species, making it suitable for stability-indicating assays. Furthermore, CE can be seamlessly integrated with Laser-Induced Fluorescence (LIF) or Mass Spectrometry (CE-MS), thereby enhancing sensitivity and enabling molecular identification of degradation products. The use of non-denaturing conditions also allows CE to retain native protein conformations during analysis, which is beneficial for studying folding and conformational stability—key factors affecting bioactivity and immunogenicity.

In biopharmaceutical quality control, CE has proven effective in lot-to-lot consistency testing, biosimilar comparability, and stability studies under ICH (International Council for Harmonisation) guidelines. Regulatory agencies increasingly recognize CE-based methods as part of the analytical toolbox for biotherapeutics, particularly when combined with orthogonal techniques like SEC and LC-MS. The development of automated CE platforms and microfluidic CE devices further facilitates high-throughput stability screening in drug discovery and process development environments. These innovations significantly reduce analysis time and sample consumption while improving reproducibility and data traceability [2].

Conclusion

Capillary electrophoresis represents a versatile, high-resolution, and reliable analytical technique for monitoring the stability of protein-based drugs throughout their development and lifecycle. Its unique ability to resolve charge and size variants, detect early-stage degradation, and operate under native or denaturing conditions makes it indispensable in the biopharmaceutical industry. As protein therapeutics become increasingly complex, and regulatory scrutiny intensifies, CE's role in ensuring product quality, safety, and efficacy will only grow stronger. Continued advances in instrumentation, method development, and coupling technologies will further enhance its applicability in both routine quality control and in-depth research investigations. Ultimately, the integration of CE into comprehensive stability monitoring programs contributes significantly to the successful development and delivery of safe, stable, and effective protein therapeutics.

Acknowledgement

None.

Conflict of Interest

None.

References

1. Aktas, Emel, Kucuksezer, Umit Cigen and Bilgic, Sevgi. "Relationship between CD107a expression and cytotoxic activity." *Cell Immunol* 254 (2009): 149–154.

***Address for Correspondence:** John Mwangi, Department of Informatics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Torun, Poland; E-mail: john@mwangi.pl*

Received: 01 February, 2025, Manuscript No. jbabm-25-168523; **Editor Assigned:** 03 February, 2025, PreQC No. P-168523; **Reviewed:** 17 February, 2025, QC No. Q-168523; **Revised:** 22 February, 2025, Manuscript No. R-168523; **Published:** 28 February, 2025, DOI: 10.37421/1948-593X.2025.17.474

2. Fregni, Guillaume, Messaoudene, Meriem, Fourmentraux-Neves, Elise, et al. "Phenotypic and functional characteristics of blood natural killer cells from melanoma patients at different clinical stages." *PLoS ONE* 8 (2013): e76928.

How to cite this article: Mwangi, John. "Application of Capillary Electrophoresis in Monitoring Protein Drug Stability." *J Bioanal Biomed* 17 (2025): 474.