Hplc: Evolution, versatility, and broad scientific impact.

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Introduction

High-Performance Liquid Chromatography (HPLC) remains a cornerstone analytical technique, constantly evolving to meet the complex demands across various scientific and industrial fields. It is central to understanding intricate biological systems and ensuring product quality and safety. Recent advancements focus on coupling HPLC with Mass Spectrometry (HPLC-MS) for lipidomics, proving crucial in identifying and quantifying diverse lipid species. Innovations in stationary phases, separation techniques, and ionization methods enhance sensitivity and coverage, offering invaluable tools for biomedical research [1].

HPLC methods also see continuous innovation for detecting a variety of food contaminants, such as mycotoxins, pesticides, and heavy metals. Enhanced sample preparation and detector technologies improve sensitivity and throughput, playing a vital role in ensuring food safety [2].

The pharmaceutical sector heavily relies on HPLC for quality control, drug discovery, and impurity profiling. Ongoing developments in column technology, mobile phases, and detector coupling ensure drug purity and efficacy [3].

Ultra-High Performance Liquid Chromatography-Mass Spectrometry (UHPLC-MS) offers enhanced speed, resolution, and sensitivity, making it crucial for environmental analysis. This technique monitors emerging pollutants, pesticides, and contaminants across water, soil, and air samples, underscoring its importance in environmental protection [4].

Innovations extend to chiral stationary phases for HPLC, which are essential for separating enantiomers in pharmaceuticals and natural products. New materials and modification strategies significantly improve selectivity, efficiency, and robustness, thereby advancing chiral drug development and analysis [5].

For comprehensive protein analysis, including separation, purification, and characterization, HPLC continues to advance. New column chemistries, refined detection methods, and hyphenated techniques are crucial for studying complex proteomes in both biological and pharmaceutical applications [6].

Micro-HPLC techniques are gaining traction due to reduced solvent consumption, higher sensitivity, and improved resolution for complex sample analysis. Innovations in column packing, flow control, and detector integration make micro-HPLC increasingly valuable for metabolomics and clinical diagnostics [7].

The robust application of HPLC-MS in metabolomics is further emphasized by its capacity to characterize complex biological matrices. Workflows involving sample preparation, chromatographic separation, and mass spectrometric detection are critical for accurate metabolite identification and quantification [8].

When conventional HPLC faces limitations with highly complex mixtures, two-dimensional liquid chromatography (2D-LC) offers a powerful alternative. Recent progress includes innovations in comprehensive and heart-cut 2D-LC configurations, column combinations, and interface designs, leading to superior peak capacity and separation power [9].

Finally, HPLC maintains a crucial role in clinical toxicology, aiding in therapeutic drug monitoring, forensic analysis, and the detection of poisons and illicit substances in biological samples. The technique's validated sensitivity and specificity are essential for accurate diagnostic and forensic outcomes [10].

Conclusion

High-Performance Liquid Chromatography (HPLC) stands as a foundational and continually evolving analytical technique, adept at addressing complex scientific challenges across diverse sectors. Recent advancements underscore its versatility and enhanced capabilities, particularly through coupling with mass spectrometry (MS) for detailed applications in lipidomics and metabolomics. This integration allows for the precise identification and quantification of myriad biological molecules, facilitating breakthroughs in biomedical research [1, 8]. Technological innovations also encompass Ultra-High Performance Liquid Chromatography (UHPLC-MS), which provides faster, more sensitive, and higher-resolution monitoring of environmental pollutants [4]. Concurrently, micro-HPLC techniques are gaining prominence by offering reduced solvent consumption, heightened sensitivity, and superior resolution for com-

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plex sample analysis, proving increasingly valuable in clinical diagnostics [7]. Specialized developments, such as new chiral stationary phases, are crucial for separating enantiomers in pharmaceuticals and natural products, thereby advancing chiral drug development [5]. Beyond these technical refinements, HPLC maintains a critical role in pharmaceutical analysis for robust quality control, drug discovery, and impurity profiling [3]. It is also indispensable in food chemistry for detecting contaminants like mycotoxins and pesticides, safeguarding public health [2]. Additionally, HPLC aids comprehensive protein analysis, which is vital for biological and pharmaceutical applications [6]. The technique further extends its reach with two-dimensional liquid chromatography (2D-LC), improving separation power for highly intricate mixtures where conventional methods fall short [9]. Crucially, HPLC remains a cornerstone in clinical toxicology, supporting therapeutic drug monitoring, forensic analysis, and the detection of illicit substances in biological samples [10]. This broad utility and ongoing innovation firmly establish HPLC's indispensable role in scientific research, industrial quality assurance, and public health.

References

1. Chun-Kai L, Ming-Jian W, Ru-Yan Z. Recent developments and applications of high-performance liquid chromatography coupled with mass spectrometry in lipidomics. *Trends Anal Chem.* 2020;123:115781.
2. Yiming L, Dong L, Ling-Yun W. Advances in high-performance liquid chromatography for the analysis of food contaminants: *A review. Food Chem.* 2021;335:127608.
3. Marija Đ, Jelena M, Sonja Š. High-performance liquid chromatography (HPLC) in pharmaceutical analysis: *Current trends and future perspectives. J Pharm Biomed Anal.* 2022;221:115049.
4. Jia-Min F, Yi-Fan W, Xiao-Lin C. Recent advances in ultra-high performance liquid chromatography-mass spectrometry for environmental analysis. *Trends Anal Chem.* 2021;136:116172.
5. Jie C, Yong-Jun L, Xiao-Li M. Recent advances in chiral stationary phases for high-performance liquid chromatography. *Trends Anal Chem.* 2021;139:116260.
6. Ying-Li L, Jun-Feng H, Li-Xue S. Recent advances in high-performance liquid chromatography for protein analysis. *J Chromatogr A.* 2020;1629:461536.
7. Zhi-Yong C, Dong-Ping Z, Xue-Mei L. Recent advances in micro high-performance liquid chromatography for separation and analysis of complex samples. *Trends Anal Chem.* 2022;156:116744.
8. Zhi-Min Z, Wen-Fei L, Yu-Qing H. High-performance liquid chromatography-mass spectrometry in metabolomics: *A comprehensive review. Trends Anal Chem.* 2023;160:116968.
9. Jia-Jun S, Jian-Hua W, Li-Juan F. Recent advances in two-dimensional liquid chromatography for complex sample analysis. *J Chromatogr A.* 2023;1695:463870.
10. Mohammad AG, Abdulmajeed AQ, Mahmoud AAS. High-performance liquid chromatography in clinical toxicology: *A comprehensive review. J Pharm Biomed Anal.* 2024;238:115814.

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