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The Use of Gas Chromatography in the Analysis of Pharmaceutical Compounds: A Literature Review

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ABSTRACT

Background & Objective: This review examines key advancements and applications of gas chromatography in pharmaceutical drug analysis by exploring innovations in instrumentation, sample-preparation strategies, and analytical performance across biological and non-biological matrices. The primary objective is to summarize recent progress in GC, GC-MS, and GC-MS/MS technologies and evaluate their effectiveness in detecting volatile and semi-volatile compounds, impurities, residual solvents, and degradation products. **Method:** A systematic search of indexed literature from 2015 to 2025 was performed using predefined inclusion criteria involving thematic relevance, completeness of data, and the direct application of GC methods. **Result:** Findings indicate that column selection, detector type, extraction approaches, and derivatization techniques markedly influence sensitivity, linearity, and quantification accuracy for analytes such as sibutramine, favipiravir, diclofenac, volatile anesthetics, cannabinoids, and phytochemicals. The discussion highlights that hybrid technologies, precise temperature programming, and optimized sample clean-up substantially enhance analytical performance. **Conclusion:** The review concludes that gas chromatography remains a critical analytical platform for pharmaceutical quality control and drug-stability evaluation across research and clinical settings.

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Introduction

Chemical analysis in the pharmaceutical industry is advancing rapidly with the adoption of high-throughput technologies, automation, and chemometric approaches

that enhance the efficiency of drug development processes and the quality of final products. Direct process monitoring via process analytical technology enables real-time oversight of downstream stages such as crystallization and drying, while continuous-flow systems accelerate the synthesis and evaluation of compounds. The integration of these various innovations strengthens compliance with regulatory standards and accelerates the transition from design to validation, thereby opening the door to advanced analytical methods such as gas chromatography (Zacharis & Markopoulou, 2020).

Gas chromatography serves as the primary technique for separating both volatile and semi-volatile pharmaceutical compounds by utilizing a stationary phase and precise control of operating conditions. Recent advancements include the use of GC-GC coupled with high-tech detectors to enhance the analytical capabilities for complex mixtures in pharmaceutical research. This technique is also effective in handling residual solvents and specific functional groups through derivatization processes, particularly when samples are sensitive to heating conditions (Zaid et al., 2023). This increasingly widespread application serves as a crucial foundation for compound characterization.

Gas chromatography plays a strategic role in ensuring the purity of pharmaceutical compounds by detecting trace impurities, nitrosamines, and degradation products, thereby meeting the requirements of standards such as ICH, FDA, and EMA. The use of hybrid methods such as GC-MS supports accurate quantification of volatile organic contaminants and diastereomers in modified APIs. This approach strengthens stability evaluation and impurity profiling—key aspects of drug safety assurance—while complementing the separation function (Goyon, 2024).

Some pharmaceutical compounds that can be analyzed by gas chromatography are as follows. Sibutramine, or chemically known as 1-(1-(4-chlorophenyl)-cyclobutyl)-3-methylbutyl-N,N-dimethylamine, has a characteristic structure consisting of a cyclobutyl core bonded to a chlorophenyl group and a butyl chain ending in dimethylamine, resulting in a lipophilic and volatile molecule under controlled conditions, making it suitable for analysis by gas chromatography following appropriate extraction and derivatization processes. Its main characteristics are the presence of a chlorine atom on the phenyl ring and a tertiary amine group that confers weak basic properties, making it easy to engineer into a stable volatile form; it is this characteristic that makes this compound frequently detected in counterfeit weight-loss supplements (Kozhuharov et al., 2023).

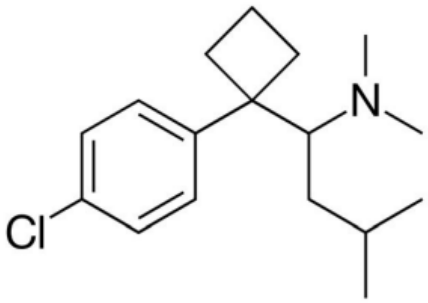

FIGURE 1. Structure of Sibutramine (Kozhuharov et al., 2023)

Favipiravir, with the chemical name 6-fluoro-3-oxo-3,4-dihydropyrazine-2-carboxamide, has a pyrazine skeleton substituted with fluorine and an amide group, resulting in a small heterocyclic structure that is relatively stable to heating, thus

enabling GC-based analysis of its derivatives. The nitrogen-rich pyrazine core makes it less volatile in its native state, but modification through derivatization can enhance its ability to be vaporized and separated on a GC column, while the presence of fluorine also provides good detection power as its response to certain detectors is increased (R. Jain et al., 2023).

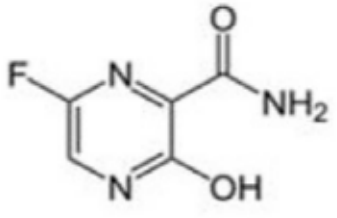

FIGURE 2. Structure of Favipiravir (R. Jain et al., 2023)

Diclofenac, or sodium 2-(2,6-dichlorophenyl)-aminophenylacetate, carries two chlorine atoms on the phenyl ring and an aromatic amine group linked to the acetate chain, resulting in a chlorinated aromatic structure that is stable enough to be analyzed via GC-MS after derivatization to reduce its polarity. The two interconnected aromatic rings and the chlorine substituents provide sufficient volatility when heated, while the carboxyl group must be modified beforehand so that the compound can pass through the GC column without degradation, making it a frequently tested candidate in pharmacokinetic studies using GC techniques (Shah et al., 2016).

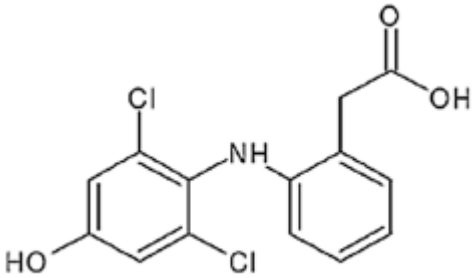

FIGURE 3. Structure of the Analgesic Diclofenac (Shah et al., 2016)

Gas chromatography has evolved into a highly strategic analytical technique in pharmacy, particularly for volatile and semi-volatile compounds that require high-precision separation. Although various studies have reported on the optimization of analytical conditions and method validation, variations in technical approaches and operational parameters often result in differences in data quality that need to be comprehensively evaluated. The consistency of results, detection sensitivity, and the method's relevance to regulatory requirements are critical issues that demand systematic examination. Therefore, this literature review was prepared to summarize the latest findings, assess the strengths and limitations of the methods, and identify opportunities for the development of gas chromatography applications in the analysis of pharmaceutical compounds. This review is intended to serve as a critical reference for researchers, analysts, and method developers in the field of analytical pharmacy.

Objective

The primary objective is to summarize recent progress in GC, GC-MS, and GC-MS/MS technologies and evaluate their effectiveness in detecting volatile and semi-volatile compounds, impurities, residual solvents, and degradation products.

Method

The research methodology for this review was developed through a systematic search of scientific articles indexed in reputable databases, including MDPI, Elsevier, Frontiers, NCBI, and Google Scholar, covering the publication period from 2015 to 2025. Of the total 25 articles identified in the initial stage, 22 met the inclusion criteria: they discussed the use of gas chromatography for analyzing pharmaceutical compounds, provided experimental data or method evaluations, and were available in full text. Articles were excluded if they were unrelated to the analysis of pharmaceutical compounds, did not directly use gas chromatography methods, consisted solely of opinions or editorials, or were not accessible in full text. The selection process was conducted through a stepwise review of the titles, abstracts, and content of the articles to ensure relevance to the review's objectives. This approach enabled the development of a focused, consistent analysis aligned with the evolution of gas chromatography methodology over the past decade. The keywords used were gas chromatography, GC-MS, pharmaceutical compound analysis, drug purity, impurities, and volatiles.

Results

Gas chromatography is described in the literature as an analytical separation technique that works by vaporizing the sample and then carrying the analyte molecules through a heated column using an inert gas such as helium or nitrogen, thereby allowing components distributed between the stationary phase and the mobile phase to be separated efficiently. Its basic principle relies on two stationary phases—a solid adsorbent in gas-solid chromatography and a liquid layer in gas-liquid chromatography—each providing distinct retention characteristics, as developed since the discoveries by James and Martin in the early 1950s. This technique has advanced rapidly due to its ability to analyze highly volatile and thermally stable compounds, enabling the use of sensitive detectors, small sample sizes, and integration with mass spectrometry to enhance both qualitative and quantitative analysis, thereby expanding its applications from toxicology and illicit drugs to the assessment of the purity of organic mixtures. Although it offers speed, high resolution, and good quantitative accuracy, GC remains limited by the volatility and thermal stability requirements of the sample, as well as potential issues with certain stationary phases, such as bleeding events in gas-liquid chromatography systems (Nikam et al., 2025).

TABLE 1. Results of the Article Review

No	Author (Year)	Main Sample	Matrix	Sample Preparation	GC Parameters	Detector	LOQ	% Recovery
1	Kozhuharov et al. (2023)	Sibutramine	Dietary supplement	Methanol dissolution; ultrasonication; filtration	BR-5ms column 15 m × 0.25 mm × 0.25 µm; carrier gas He 1 mL/min; splitless injector; oven 60°C for 1 min then 160°C and 225°C; injection volume 1 µL; transfer line 300°C	MS EI	0.5488 µg/mL	100–102%
2	R. Jain et al. (2023)	Favipiravir	Plasma; blood; urine	FPSE sol-gel PEG; MeOH elution; BSTFA derivatization	SH Txi 5SilMS column 30 m × 0.25 mm × 0.25 µm; carrier gas He 1 mL/min; injector 250°C split 10; oven 90°C then 300°C; run time 15 min; transfer line 250°C	MS EI	0.003–0.0086 µg/mL	93–103%
3	Pyo (2016)	Propofol	Plasma	MCX SPE; methanol elution	HP-5MS column 30 m × 250 µm × 1 µm; splitless injector 250°C; oven 80°C then 290°C; ion source 230°C; interface 250°C	MS EI	25 ng/mL	96.6–99.4%
4	Lin et al. (2015)	Sevoflurane	Arterial blood	Headspace; direct injection	HP-5 column 30 m × 0.32 mm × 0.25 µm; oven 40°C then 200°C; injector 250°C; inlet pressure 349 kPa; helium flow 25 mL/min	FID	NA	Concentration 0.36%
5	Ciucă-Anghel et al. (2022)	Methadone; EDDP	Plasma; urine	LLE	General GC-MS conditions; non-polar phase column; He carrier gas; injector adjusted according to method	MS	NA	Concentrations 4.366 µg/mL, 3.012 µg/mL, and 6.697 µg/mL
6	Wei & Su (2022)	Fentanyl and 8 other fentanyl analytes	Hair	Methanol HCl extraction; sonication at 40°C; N2 drying; mobile phase reconstitution	DB-5MS column 30 m × 0.25 mm × 0.25 µm; temperature 180°C for 1 min then 300°C; helium flow 1 mL/min; injector 280°C split 5:1; injection volume 1 µL; EI 70 eV; ion source 230°C; interface 250°C	MS	0.02–0.05 ng/mg	>86%

No	Author (Year)	Main Sample	Matrix	Sample Preparation	GC Parameters	Detector	LOQ	% Recovery
7	Guntner et al. (2019)	Propofol	Cerebral microdialysate	DI-SPME	HP-5MS column 30 m × 0.25 mm × 0.25 µm; carrier gas He 1.5 mL/min; splitless injector; oven 60°C for 1 min then 30°C/min to 225°C followed by 75°C/min to 300°C and held for 5 min	MS	LOD 50 ng/L	NA
8	Bonchev et al. (2017)	Amphetamine; Methamphetamine	Blood	SPE and PFPA derivatization	HP-5MS column 30 m × 0.25 mm × 0.25 µm; carrier gas He 1.5 mL/min; splitless injector 250°C; oven 50°C for 0.5 min then 3°C/min to 200°C followed by 4°C/min to 320°C	MS	AMP LOD 25 ng/mL; MET LOD 10 ng/mL	NA
9	Yasien et al. (2022)	Morphine, Codeine, 6-Acetylmorphine, Nalbuphine, Tramadol, Dextromethorphan	Blood; urine	dSPE with Epsom salt plus phosphate buffer pH 6 followed by BSTFA derivatization	Agilent J&W column 15 m × 0.25 mm × 0.25 µm; carrier gas He 8 psi; splitless injector 220°C; oven 100°C for 3 min then 50°C/min to 250°C held for 2 min followed by 60°C/min to 310°C held for 5 min	MS	LOQ 10 ng/mL for morphine, codeine, nalbuphine, tramadol, dextromethorphan; LOQ 5 ng/mL for 6-acetylmorphine	NA
10	Bodur et al. (2021)	Hydroxychloroquine sulfate	Serum; urine; saliva	UA-SFDF-LPME after protein precipitation	HP-5MS column 30 m × 0.25 mm × 0.25 µm; helium gas 2.8 mL/min; splitless injector 290°C; oven 100–300°C	MS	LOQ 2.4 mg/kg; LOD 0.7 mg/kg	93.1–105%
11	Peng et al. (2020)	Caffeine	Beverage	No extraction; direct application of 5 µL to thermal desorption unit	HP-5MS column 15 m × 0.25 mm × 0.25 µm; helium 1 mL/min; injector 240°C split 10:1; oven 100–280°C	MS	LOD 0.456 µg/mL	93.4–95%
12	Andrenyak et al. (2017)	THC; OH-THC; COOH-THC; CBD	Plasma	Acetonitrile precipitation; LLE (hexane:ethyl acetate 9:1);	DB1-MS column 30 m × 0.25 mm × 0.1 µm; helium; Agilent 7890A injector; oven adjusted according to method	MS/MS	THC and OH-THC LOQ 0.1 ng/mL; CBD 0.25 ng/mL; COOH-THC 0.5 ng/mL	83.5–118%

No	Author (Year)	Main Sample	Matrix	Sample Preparation	GC Parameters	Detector	LOQ	% Recovery
				MSTFA derivatization				
13	Ellefsen et al. (2015)	Cocaine and benzoylecgonine	Venous blood	SPE	Primary column DBS-1MS 15 m × 0.25 mm × 0.25 µm; secondary column ZB-50 30 m × 0.32 mm × 0.25 µm; He carrier gas; splitless injection 2 µL; total analysis time 18.63 min	MSD	LOQ 1 µg/L	21.4–105.9%
14	B. Jain et al. (2022)	DIC, IBU, NAP, KET	Urine	FPSE after MCF derivatization	GC-MS column details not fully described; MeOH elution 0.5 mL; standard GC-MS carrier gas	MS	LOQ 0.016–0.0103 µg/mL; LOD 0.0049–0.0015 µg/mL	Absolute recovery 86.6–113.1%
15	Krokos et al. (2018)	NSAIDs	Human serum	LLE with ethyl acetate; BSTFA TMCS 1% derivatization	HP-5ms UI column 30 m × 0.25 mm × 0.25 µm; He carrier gas; PTV injector 200–320°C; temperature program 120°C for 1 min then 300°C at 15°C/min total 15 min	MS EI	LOQ 6–414 ng/mL	88–110%
16	Di Trana et al. (2024)	HHC epimers and metabolites	Whole blood; urine; saliva	QuEChERS; β-glucuronidase hydrolysis for blood and urine; BSTFA derivatization	HP-5ms column 30 m × 0.25 mm × 0.25 µm; He carrier gas 2.25 mL/min; multimode injector 270°C; temperature program 120°C for 1 min to 300°C	MS/MS MRM	LOQ 1 ng/mL	NA
17	Darmapatni et al. (2016)	Acetaminophen	Human hair	Decontamination; homogenization; water extraction at 45°C for 2 h; BSTFA TMCS derivatization	HP-5ms column 30 m × 0.25 mm × 0.25 µm; injection 1 µL; GC-MS conditions Agilent 6890N	MS	NA	Various specimens, 0–10 cm concentration 0.2473–0.5782 ng/mg
18	Sudarma & Subhaktiyasa (2021)	Paracetamol	Blood and serum	SPE using silica gel and Whatman paper;	GC 6890N column; He carrier gas 1 mL/min; injector 250°C;	MS	NA	Paracetamol concentration in blood sample 175.2

No	Author (Year)	Main Sample	Matrix	Sample Preparation	GC Parameters	Detector	LOQ	% Recovery
				chloroform elution; drying	temperature program 70°C for 5 min increasing to 270°C			ppm and serum sample 56.7 ppm
19	Adib et al. (2017)	Camphor; Menthol; Methyl salicylate	Analgesic ointment	Two-step dilution	Capillary column 30 m × 0.25 mm × 0.25 µm; He carrier gas 3.3 mL/min; injector 250°C; split 20:1; oven 100°C increasing 20°C/min to 200°C then 230°C for 6 min	FID	Camphor 0.847 µg/mL; Menthol 0.684 µg/mL; MS 6.507 µg/mL	NA
20	Aisiyah et al. (2022)	Paracetamol	Urine	LLE with ethyl acetate followed by BSTFA TMCS 1% derivatization	Agilent 6890N; column not specified; standard GC-MS conditions; injection after derivatization	MS	NA	Methanol:ammonia TA (100:1.5 v/v), methanol:butanol TAF (60:40 v/v)
21	Dhouibi et al. (2018)	Metabolite compounds of Urtica dioica	Ethanolic extract	Maceration followed by evaporation	DB5 column 30 m × 0.25 mm × 0.25 µm; oven 50°C for 1 min increasing 3°C/min to 250°C for 5 min then 2°C/min to 280°C for 3 min; injector 250°C; split 30:1; N2 carrier gas	MS	NA	Activity at doses of 200 mg/kg and 400 mg/kg
22	Shah et al. (2016)	Diclofenac	Human plasma	LLE with n-hexane; deproteinization with phosphoric acid and acetone; PFPA derivatization	BP1 column 15 m × 250 µm × 0.25 µm; He carrier gas 1.2 mL/min; injection 2 µL; splitless; injector 280°C; oven 150°C held for 4 min then 4°C/min to 180°C held for 0.5 min followed by 60°C/min to 300°C; ion source 230°C; transfer line 280°C	MS (SIM)	LOQ 0.25 ng/mL; LOD 0.125 ng/mL	89–95%

Discussion

Various studies show that gas chromatography (GC) continues to be used to identify the profiles of pharmaceutical compounds with increasing precision. A study by Kozhuharov (2023), for example, highlights how GC-MS in Selected Ion Monitoring mode can detect sibutramine in supplements with high accuracy, even when levels are in the microgram range. The Bruker Scion 436-GC SQ MS instrument used provided rapid separation within 12 minutes, with ion stability at 114, 72, and 58 m/z serving as the basis for quantification. Test results from six sibutramine-positive samples showed an extreme range of concentrations, reflecting the method's ability to sharply detect concentration variations. This approach differs in nuance from other techniques that place greater emphasis on the extraction stage as a source of increased sensitivity. According to Jain et al. (2023), the combination of fabric phase sorptive extraction and GC-MS is actually key to revealing favipiravir levels in plasma, blood, urine, and even forensic samples. The Shimadzu Nexis GC-2030 instrument used operates on a 15-minute analysis run with an SH-Txi-5Sil MS column, while utilizing BSTFA derivatization for the stability of volatile analytes. A linearity range of 0.01–10 µg/mL and a detection limit as low as 0.001 µg/mL demonstrate the instrument's high responsiveness to the enhanced extraction efficiency of the PEG sol-gel membrane. When compared to the results of sibutramine testing, this method's ability to handle complex biological matrices appears more dominant due to the support of a more extensive pre-analytical process.

Research by Pyo (2016) offers a different perspective as its focus lies on the purity of the propofol extraction process prior to entering the GC-MS instrument. By utilizing an MCX cartridge, the analyte can be directly injected with methanol without an evaporation step that could potentially cause propofol loss. The Agilent 7890A–5975C system used operates within a scan range of 50–550 amu, allowing for the selective detection of compounds with low volatility. Stable accuracy and precision within the ±10% range indicate that even without derivatization, GC-MS performance remains reliable when instrumental and extraction conditions are appropriately adjusted. These results contrast with the method by Jain et al., which heavily relies on derivatization for the stability of volatile analytes. In a clinical study by Lin et al. (2015), GC was used to correlate arterial blood sevoflurane levels with end-tidal concentrations during the emergence phase from anesthesia. The HP 6890 instrument with a headspace sampler provided a clean analytical pathway for volatile anesthetic compounds, using an HP-5 column and an FID detector sensitive to small concentration changes. A temperature ramp-up profile to 200°C enabled rapid separation aligned with the dynamics of the patient's blood gas distribution.

Another approach is proposed by Yasien et al. (2022) and Bodur (2021), who utilize dSPE or LPME as pre-extraction techniques prior to injection into GC-MS. Both studies selected SIM mode and an HP-5MS column, but their test results showed different characteristics. According to Yasien et al. (2022), a combination of Epsom salt, acetonitrile, and BSTFA achieved opioid separation with an analysis time of just 14 minutes and a sensitivity of up to 5 ng/mL for 6-acetylmorphine, while Bodur's method (2021) demonstrated that ultrasonication-assisted LPME can enhance hydroxychloroquine detection sensitivity by approximately 440-fold compared to direct injection.

According to Peng et al. (2020), a different approach was offered via a thermal desorption–GC/MS system that enables caffeine analysis without extraction, even

with just a 5 µL sample injection. The CDS 5200 pyrolysis instrument, connected to an Agilent 6890–5973 system, operates with two heating stages: drying at 80°C and desorption at 250°C, before the analyte vapor is directed into a 15-meter HP-5MS column. The linear response obtained in the range of 10–500 µg/mL and a theoretical LOD of 0.456 µg/mL indicate that direct heating is capable of producing sufficient volatility to detect caffeine without complex sample preparation. The absence of interference from beverage components or common pharmaceuticals indicates that rapid separation via a 40°C/min temperature ramp still maintains adequate resolution in full-scan mode. Andrenyak et al. (2017) developed a far more complex method when analyzing THC, CBD, and their metabolites using GC-MS/MS triple quadrupole. The Agilent 7890A instrument paired with a 7000 QqQ detector required a more aggressive stepwise temperature programming, coupled with the use of a DB-1MS column with a film thickness of only 0.1 µm to improve the separation efficiency of cannabinoid compounds with differing polarities and volatilities. SRM mode allows for the monitoring of specific ion transitions (e.g., 371–289 for THC), ensuring accuracy is maintained even when plasma samples have complex matrices. Sufficient sensitivity to detect THC and OH-THC residues following high-dose CBD consumption demonstrates that triple quadrupole instrumentation offers a level of selectivity control unattainable with single-quadrupole GC-MS.

Research by Ellefsen et al. (2015) demonstrates how a two-column configuration—DBS 1MS as the initial column and ZB-50 as the subsequent column—promotes more targeted separation of cocaine and benzoylecgonine, especially when helium flow and splitless injection mode are combined with an MS detector to maintain peak sharpness throughout the 18.63-minute total analysis time. According to Jain et al. (2022), a significantly more streamlined approach was achieved via FPSE following chloroformate methyl derivatization, and although column details were not fully provided, the combination of 0.5 mL methanol eluent injection with a standard GC-MS system yielded sub-nanogram detection limits and broad recovery.

Krokos et al. (2018) relied on LLE followed by BSTFA-TMCS derivatization and used an HP-5ms UI column to detect various serum NSAIDs via a PTV injector with a swing range of 200 to 320°C, such that a more aggressive oven temperature programming of 120 to 300°C provided sufficient separation space for compounds with similar polarity. In Di Trana et al. (2024) added a layer of complexity with QuEChERS, β-glucuronidase hydrolysis, and MRM-based GC-MS/MS, enabling the monitoring of HHC epimers and metabolites in blood, urine, and saliva at a helium flow rate of 2.25 mL/min, making their chosen HP-5ms configuration more selective than single-quadrupole GC-MS. According to Darmapatni et al. (2016), the detection of acetaminophen in hair requires a series of decontamination, homogenization, and BSTFA derivatization steps so that the HP-5ms column can detect concentrations as low as 0.5782 ng/mg without interference from the keratin matrix.

Sudarma and Subhaktiyasa (2021) used a similar configuration to profile paracetamol in blood and serum, but their preparation method shifted to silica gel-based SPE and Whatman paper prior to injection into a GC 6890N with a temperature program of 70–270°C, yielding significantly different concentration values between blood and serum. In topical formulations, Adib et al. (2017) instead utilized an FID with a 30-m capillary column and a helium flow rate of 3.3 mL/min, enabling the separation of camphor, menthol, and methyl salicylate via a gradual temperature ramp of 100–230°C without the need for derivatization. Aisiyah et al. (2022) processed

urine samples containing paracetamol via ethyl acetate LLE and BSTFA derivatization, then injected them into an Agilent 6890N GC-MS; although column details were not specified, stable elution patterns in two comparative solvent systems indicated that derivatization optimization could compensate for the lack of column specification information in that test.

Research by Dhouibi et al. (2018) utilized a DB-5 column with a temperature program that increased gradually by only 3°C per minute to 250°C, followed by 2°C per minute to 280°C, allowing the metabolite profile of Urtica dioica to be separated smoothly even though injection was performed under 30:1 split conditions and the carrier gas used was nitrogen rather than helium. According to Shah et al. (2016), the need for much higher sensitivity in the analysis of plasma diclofenac led them to choose a shorter BP1 column and combine it with splitless mode and PFPA derivatization before performing GC-MS in SIM,

Conclusion

The conclusion of this article emphasizes that gas chromatography is a crucial analytical tool for the characterization of pharmaceutical compounds, as it provides selective separation, high sensitivity, and accurate quantification for a wide range of volatile and semi-volatile molecules. The integration of hybrid techniques such as GC-MS, GC-MS/MS, SPME, LPME, and various derivatization strategies enables this method to handle complex matrices, improve detection limits, and expand the scope of analysis from illicit drugs, therapeutic compounds, and metabolites to critical impurities relevant to regulation. A variety of research results indicate that the selection of columns, detectors, and sample pretreatment significantly determines the success of separation and data consistency; therefore, the optimization of operational parameters is a key aspect that cannot be overlooked. Overall, gas chromatography offers high reliability for evaluating the purity, stability, and analytical profile of drugs, and provides extensive opportunities for the development of advanced methods that are more adaptable to the needs of the modern pharmaceutical industry.

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