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Review Article

A Concise Review - An Analytical Method Development and Validation of Vildagliptin

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Abstract

Vildagliptin is an orally active, potent, and selective Dipeptidyl Peptidase-4 (DPP-4) inhibitor, shown to be effective and well tolerated in patients with Type 2 Diabetes Mellitus (T2DM) as either monotherapy or in combination with other anti-diabetic agents. Vildagliptin is used to treat type 2 diabetes mellitus, typically in conjunction with diet and exercise. Vildagliptin is usually administered orally, with a common dosing regimen of 50 mg twice daily. It can be taken with or without food; however, it is important to take it consistently at the same time each day for optimal effectiveness.

This study focuses on the most recent advancements in analytical methods for determining the presence of Vildagliptin in different biological media, such as human plasma and urine, as well as in bulk and commercial dose forms. The following analytical techniques will be fully investigated in this paper: High-pressure Liquid Chromatography (HPLC), High Efficiency Thin Layer Chromatography (HPTLC), liquid chromatography coupled to a tandem mass spectrometry system (LC-MS), and electrophoresis. These techniques include several parameters, such as the following: matrix, dynamic phase composition, permanent phase RF value for sensing frequency, retention duration, DL, carrier gas, flow rate, capillary wavelength, separation voltage, temperature, and pressure.

More Information

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Keywords: Vildagliptin; HPLC; LC-MS/MS; HPTLC; LC-MS; Spectrophotometry; Electroanalytical method; Electrophoresis

Introduction

Vildagliptin is an orally active, potent, and selective Dipeptidyl Peptidase-4 (DPP-4) inhibitor, shown to be effective and well tolerated in patients with Type 2 Diabetes Mellitus (T2DM) as either monotherapy or in combination with other anti-diabetic agents [1].

Vildagliptin improves Glycaemic control by inhibiting DPP-4 from inactivating the incretin hormones glucagon-like peptide 1 and glucose-dependent insulinotropic polypeptide, prolonging incretin activity in response to the ingestion of nutrients [2].

This allows for increased insulin sensitivity, decreased glucagon secretion, and improved β-cell function in a glucose-dependent manner [2].

The medication is typically administered once or twice daily due to its pharmacokinetic profile, which includes a half-life of about 90 minutes, although DPP-4 inhibition can persist for over 10 hours [3].

The chemical name for vildagliptin is (S)-1-[N-(3-hydroxy-1-adamantyl) glycyl] pyrrolidine-2-carbonitrile (Figure 1).

Pharmacodynamics of vildagliptin

Vildagliptin works to improve glycemic control in type II diabetes mellitus by enhancing the glucose sensitivity of beta-cells (β-cells) in pancreatic islets and promoting glucose-dependent insulin secretion. Increased GLP-1 levels lead

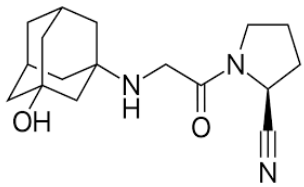

Figure 1: Vildagliptin Structure.

to enhanced sensitivity of alpha cells to glucose, promoting glucagon secretion. Vildagliptin causes an increase in the insulin to glucagon ratio by increasing incretin hormone levels; this results in a decrease in fasting and postprandial hepatic glucose production. Vildagliptin does not affect gastric emptying. It also has no effects on insulin secretion or blood glucose levels in individuals with normal glycemic control [4].

In clinical trials, treatment with vildagliptin 50-100 mg daily in patients with type 2 diabetes significantly improved markers of beta-cells, proinsulin to insulin ratio, and measures of beta-cell responsiveness from the frequently-sampled meal tolerance test [4]. Vildagliptin has improved glycated haemoglobin (HbA1c) and fasting plasma glucose (FPG) levels [5].

Pharmacokinetics of vildagliptin

Absorption: Vildagliptin is rapidly absorbed following oral administration. Peak plasma concentrations (Cmax) are typically reached within 1 to 2 hours post-dose, with some studies reporting a peak at approximately 1.1 to 1.7 hours, depending on the study design and population [3,6,7] The absolute oral bioavailability of vildagliptin is approximately 85%, indicating that a significant portion of the administered dose reaches systemic circulation in an active form [3,7] While food intake can delay the time to peak concentration (Tmax) by up to 2.5 hours and decrease Cmax by about 19%, it does not significantly affect the overall drug exposure (AUC) [3,7].

Distribution: Vildagliptin has a large Volume of distribution (Vd) of approximately 71 L, suggesting extensive distribution into extravascular spaces [7]. The drug exhibits low plasma protein binding at about 9.3%, which allows for a greater proportion of free drug available for pharmacological action [3]. Vildagliptin distributes equally between plasma and red blood cells, which may influence its pharmacodynamics [7].

Metabolism: Vildagliptin is primarily metabolized through hydrolysis, resulting in an inactive metabolite known as LAY151 (M20.7), which accounts for about 57% of the dose. This metabolic pathway is largely independent of cytochrome P450 enzymes, minimizing potential drug interactions [1,8]. Other metabolites include M15.3 (an N-amide hydrolysis product), M20.2 (an N-glucuronide), and oxidation products M21.6 and M20.9 [7,8]. Approximately 70% of vildagliptin is eliminated via metabolism, with renal clearance accounting for about 33% of total body clearance [1].

Elimination: After administration, roughly 85% of vildagliptin is recovered in urine, with about 22.6% being unchanged drug. The remaining metabolites are excreted in feces [1]. The terminal half-life of vildagliptin ranges from approximately 1.32 to 2.43 hours, supporting its dosing regimen [9,10].

Analytical account on vildagliptin

The widespread literature survey exposed multiple analytical techniques like UV spectrophotometry method, HPLC, HPTLC, LC-MS/MS, for the determination of Vildagliptin in bulk and pharmaceutical formulation. These reported methods describe the evaluation of vildagliptin in various dosage forms, like tablets and matrix-like human plasma.

Chromatographic overview

HPLC techniques: Presents a validated Reversed-phase High-performance Liquid Chromatography (RP-HPLC) method for determining vildagliptin in pure and tablet formulations. The method utilized a Thermo-hypersil ODS C18 column with a mobile phase of methanol, acetonitrile, and phosphate buffer at pH 3.5. The flow rate was set at 0.8 mL/min, with a detection wavelength of 212 nm. Calibration showed linearity in the range of 1–14 µg/mL, with an R^2 greater than 0.9919. Precision was confirmed with RSD values below 1.13%, and recovery rates ranged from 100.13% to 100.29%. Stability studies validated the method's specificity against degradation products. The analysis time was approximately 7 minutes, with vildagliptin's retention time around 5.41 minutes. Overall, the method is reliable for routine analysis and quality control in pharmaceuticals. It effectively quantifies vildagliptin in both pure and commercial tablet formulations. The study establishes a robust approach for pharmaceutical quality assurance [11].

The research article presents the Development and Validation of a reversed-phase HPLC Method for the Determination of Vildagliptin Using an Experimental Design. A simple, robust, and fast reversed-phase HPLC method was developed and validated with UV detection (210 nm) for routine determination of vildagliptin. Chromatographic analysis was performed with a mobile phase containing a mixture of 10 mM phosphate buffer (pH 4.6) and acetonitrile (85:15, v/v) with a flow rate of 1.0 mL/min. The procedure was validated as per International Conference on Harmonization (ICH) guidelines for linearity (correlation coefficient r^2 = 0.999), accuracy, intermediate precision, and robustness [12].

The research article presents the development and validation of a Reversed-phase High-performance Liquid Chromatography (RP-HPLC) method for estimating vildagliptin in pharmaceutical tablet dosage forms. The methodology utilized a Shimpack VP-ODS column (150 × 4.6 mm, 5 µm) with a mobile phase of 0.02M phosphate buffer (pH 4.6) and acetonitrile in an 80:20 ratio, at a flow rate of 1.2 mL/min and detection wavelength of 210 nm. The method yielded a linear calibration curve over the concentration range of 20–70 µg/mL, with a strong correlation coefficient (R^2). Precision was confirmed with a Relative Standard Deviation (%RSD) of 0.464%, while recovery studies indicated accuracy rates close to 100%. Robustness evaluations showed satisfactory results under slight variations in conditions. Validated according

to ICH guidelines, the method is accurate, precise, and cost-effective for routine analysis. Overall, this RP-HPLC method is suitable for quality control of vildagliptin in pharmaceutical formulations, ensuring compliance with regulatory standards [13].

A new, simple, specific, precise, and accurate reversed-phase liquid chromatography method has been developed for the determination of Vildagliptin (VLG) in pharmaceutical dosage form. The separation was achieved on a Xterra® Waters C18 column (150 mm×4.6 mm, 5 µm) using mobile phase consisting of a mixture of aqueous phase (1 ml of 25% ammonium hydroxide was dissolved in 1000 ml of water for chromatography, pH of the solution was adjusted to the value of 9.5 using a 50%solution of phosphoric acid) and organic phase (methanol) in the ratio of 60:40 v/v at a flow rate of 1.0 ml/min. Detection was carried out at 210nm. The retention time of Vildagliptin was found to be 6.3 min. The calibration curve was found linear between 5-200µg/ml (r^2 = 0.9997). The limit of detection and limit of quantitation were 1.47 and 4.90 µg/mL, respectively [14].

The article titled "stability-indicating HPLC-MS method for Vildagliptin effectively separates the drug from its degradation products under stress conditions". Degradation percentages observed were 13.27% (acidic), 14.76% (alkaline), 23.76% (oxidative), and 1.98% (photolytic), indicating minimal light-induced degradation. The method demonstrated linearity between 2–12 µg/mL (R^2 = 0.9998), with Limits of Detection (LOD) at 3.61 µg/mL and Quantification (LOQ) at 10.96 µg/mL. Precision and accuracy results showed excellent repeatability (RSD < 2%) and recoveries between 99%-101%. Mass spectrometry was used to identify degradation products and possible degradation pathways [15].

The present study was aimed at developing a rapid, accurate, linear, sensitive, and validated stability-indicating High-performance Liquid Chromatographic (RP-HPLC) method for the determination of vildagliptin and metformin in pharmaceutical dosage form. The chromatographic separation was performed on a Kromasil-C18 column (4.5 x 250 mm; 5 µm) using a mobile phase consisting of 0.05mmol potassium dihydrogen phosphate buffer: acetonitrile (80:20 v/v), (pH adjusted to 3.5 using orthophosphoric acid). The flow rate is 0.9ml/min, and the detection was carried out at 263 nm. The chromatographic conditions, the peak retention times of metformin and vildagliptin were found to be 2.215 min and 2.600 min, respectively. The limit of detection and quantification was found to be 0.0182 µg/ml and 0.0553 µg/ml for vildagliptin and 0.4451 µg/ml and 1.3490 µg/ml for metformin, respectively [16].

The Main Objective of the present analytical research work was to develop and validate an RP-HPLC method for the estimation of Vildagliptin in bulk and dosage form. The RP-HPLC method for Vildagliptin was developed using column Phenomenex C18 column (5 µm, 250 mm × 4.6 mm) as a stationary phase and Methanol: water (60:40 v/v) (pH 4.5 adjusted with OPA) as a mobile phase. The mobile phase was maintained at a flow rate of 0.8 ml/min, and the volume of injection was 20 µl. Detection was carried out at 207 nm. The method was validated by the ICH guidelines. LOD was found to be 0.98. LOQ was found to be 2.98 [17].

Abu Dayyih, et al. performed a Reverse Phase-high Performance Liquid Chromatography (RP-HPLC) method has been developed and validated for the simultaneous analysis of vildagliptin and metformin hydrochloride in pharmaceutical dosage forms. This method is characterized by its simplicity, rapidity, and accuracy, making it suitable for high-throughput analysis in pharmacokinetic and bioavailability studies. The RP-HPLC method employed a UV detector set at a wavelength of 239 nm, which is optimal for the detection of both drugs. The method demonstrated excellent linearity with regression coefficients of 0.999 for vildagliptin and 0.998 for metformin, indicating a strong correlation between peak area and concentration. The mean percentage recovery was found to be 99.6% for vildagliptin and 99.8% for metformin, confirming the method's accuracy. The LOD was determined to be 0.0040 µg/ml for vildagliptin and 0.025 µg/ml for metformin, showcasing the method's sensitivity [18].

In their research, A simple, specific, accurate, and precise reverse-phase high-performance liquid chromatographic method was developed and validated for the estimation of Vildagliptin in tablet dosage form. An Altima C18 column having 150 mm x 4.6 mm internal diameter, 5 µm particle size in isocratic mode with mobile phase containing dilute orthophosphoric acid solution, pH 2.6±0.5 as buffer, and acetonitrile (72:28 v/v) was used. The flow rate was 1.0 ml/min, and effluents were monitored at 266 nm. The retention time for Vildagliptin was 3.25 min. The method was validated for linearity, accuracy, precision, specificity, limit of detection, limit of quantification, and robustness. Limit of detection and limit of quantification were found to be 0.06 µg/ml and 0.21 µg/ml, respectively, and the recovery of Vildagliptin from tablet formulation was found to be 99.73% [19].

The present study was undertaken to develop a suitable, sensitive, and simple analytical RP-HPLC method for Bulk drug and its pharmaceutical dosage form. The RP-HPLC method was resolved using Acetonitrile: Phosphate Buffer (60:40), pH 3.6, at a flow rate of 1.0 ml/min,- UV-Visible detector with Data Ace Software, and an Inertsil C18 column. The detection was carried out at 215 nm. The retention times of Vildagliptin 3.924 minutes, the different analytical parameters such as accuracy, linearity, precision, robustness, and ruggedness were determined according to the ICH Q2B guidelines. Due to its simplicity, rapidness, high precision, and accuracy, the proposed RP-HPLC method may be used for determining vildagliptin in pure form and in tablet formulation [20].

This study describes two analytical methods, second-order derivative UV spectrophotometric by HPLC, for the determination of vildagliptin, a drug used for the treatment of type 2 Diabetes Mellitus that belongs to a therapeutic class called inhibitors of dipeptidyl peptidase 4. The methods were validated by ICH and USP requirements. Analyses by UV derivative method were performed at 220 nm, which was the zero-crossing point of excipient solutions. HPLC was optimized, and the analysis was carried out using a Zorbax Eclipse Plus RP-C8 column (150 mm × 4.6 mm, 5 µm), detection at 207 nm, and potassium phosphate buffer solution pH 7.0: acetonitrile (85:15, v/v) as mobile phase. In the dissolution test, the conditions used were 0.01 mol L-1 hydrochloric acid in 900 mL of dissolution medium, USP apparatus 2 (paddle), and 50 rpm stirring speed [21].

In this article, Forced degradation studies of vildagliptin raw material alone and in the presence of excipients using HPLC-UV analysis. AC18 - WP, 100A°, (250 mm×4.6 mm), and a 5 µm particle size column (selected based on best column performance among several columns used) was used at 40°C in a column oven, and all solutions (standard and samples) were stored in the autosampler tray at 20°C. The mobile phase was kept flowing (1 ml/min) using the gradient elution program as described in Table 1 until the baseline became stable at 208 nm. The injection volume was 100 µL. The obtained LOD and LOQ were 0.018 and 0.066 mg/mL, respectively [22].

A simple, precise, and stability-indicating reversed-phase liquid chromatography method was developed and validated for the determination of Vildagliptin (VLG) in pharmaceutical dosage form. The chromatographic separation was obtained within 6 min and was linear in the range of 20–80 mg/mL (r2 5 0.9999). The limit of detection and limit of quantitation were 0.63 and 2.82 mg/mL, respectively. The method was validated by the International Conference on Harmonization acceptance criteria for specificity, linearity, precision, accuracy, robustness, and system suitability [23].

A new, simple, specific, precise, and accurate reversed-phase liquid chromatography method has been developed for the determination of Vildagliptin (VLG) in pharmaceutical dosage form. The separation was achieved on a Xterra® Waters C18column (150 mm×4.6 mm, 5 µm) using mobile phase consisting of a mixture of aqueous phase (1 ml of 25% ammonium hydroxide was dissolved in 1000 ml of water for chromatography, pH of the solution was adjusted to the value of 9.5 using a 50% solution of phosphoric acid) and organic phase (methanol) in the ratio of 60:40 v/v at a flow rate of 1.0 ml/min. Detection was carried out at 210nm. The retention time of Vildagliptin was found to be 6.3 min. The calibration curve was found linear between 5-200µg/ml (r^2 = 0.9997). The limit of detection and limit of quantitation were 1.47 and 4.90 µg/mL, respectively. The percentage recoveries of Vildagliptin were found to be in the range of 99.11-100.62%. The method was validated by the International Conference on Harmonization acceptance criteria for specificity, linearity, precision, accuracy, robustness, and system suitability [14].

The present work describes the development of a Reverse Phase-High Performance Liquid Chromatography (RP-HPLC) method by QbD approach using Design of Experiments and subsequent validation for analysis of Vildagliptin pharmaceutical formulation. The LOD of Vildagliptin was found to be 200 ng/ml. The LOQ for Vildagliptin was found to be 600ng/ml. These values indicate that the method developed is sensitive [24].

A new, simple, accurate, and precise liquid chromatographic method has been developed and validated for the determination of two novel Dipeptidylpeptidase-4 (DPP-4) inhibitors, namely Vildagliptin (VLG) and saxagliptin HCl (SXG), simultaneously in their binary mixtures with metformin HCl (MET). Chromatographic separation was achieved on an Inertsil® CN-3 column (250 mm x 4.6 mm, 5 µm). Isocratic elution using a mobile phase of potassium dihydrogen phosphate buffer pH (4.6) - acetonitrile (15:85, v: v) at a flow rate of 1 mL/min with UV detection at 208 nm was performed. The liquid chromatographic method was used for the simultaneous determination of VLG, SXG, and MET in the range of 5-200, 0.5-20, and 50-2000 µg/mL, respectively [25].

A simple, precise, and stability-indicating HPLC method was developed and validated for the simultaneous determination of Metformin Hydrochloride (MET) and Vildagliptin (VLG) in pharmaceutical dosage forms. The method involves the use of easily available, inexpensive laboratory reagents. The separation was achieved on a Grace Cyano column (250 mm × 4.6 mm), 5 µm, with isocratic flow. The mobile phase was pumped at a flow rate of 1.0 mL/min, consisted of 25 mM ammonium bicarbonate buffer and acetonitrile (65:35, v/v). The UV detection was carried out at 207 nm. A linear response was observed over the concentration range of 25–125 µg/mL for MET and 50–250 µg/mL for VLG, respectively. The limit of detection and limit of quantification for MET were 0.36 µg/mL and 1.22 µg/mL, and for VLG were 0.75 µg/mL and 2.51 µg/mL, respectively. The method was successfully validated by ICH guidelines acceptance criteria for specificity, linearity, accuracy, precision, robustness, and system suitability. Individual drugs (MET and VLG) were exposed to thermal, photolytic, hydrolytic, and oxidative stress conditions [26].

The research article presents the development and validation of a stability-indicating Ultra-high-performance Liquid Chromatography (UHPLC) method for the simultaneous estimation of vildagliptin and dapagliflozin in bulk and marketed formulations. The method utilized an Agilent C18 column (4.6 × 100 mm) with a mobile phase composed of methanol and 0.1% orthophosphoric acid in a ratio of 78:22 at a flow rate of 1.0 mL/min, with detection occurring at 234 nm. The study included forced degradation tests under various conditions such as acid and base hydrolysis, oxidation, and

Table 1

Sr. No.	Drug	Matrix/ Dosage form	Stationary Phase	Mobile Phase	Detection (nm)	Flow Rate (ml/min)	Ret. Time (min.)	Detector	Ref No.
1.	Vildagliptin	Tablet	Agilent Eclipse XDB C18, 150 4.6mm,5m, column	Phosphate buffer and acetonitrile in the ratio of 85:15%v/v/ v	210 nm	25 micro/L	3.04 min	UV-visible detector	[11]
2	Vildagliptin	Tablet	C18 column (4.6 × 150 mm id., particle size 5 µm)	acetonitrile and phosphate buffer, pH 4.6 (15:85, v/v)	210 nm	1.0 mL/min	-	PDA detector	[12]
3	Vildagliptin	Tablet	Waters X-Bridge, C8, 150 x 4.6 mm, 5 µm	0.02M phosphate buffer (pH 3) and acetonitrile in an 80:20 ratio	210nm	1.2 mL/min	6.5 min	UV-visible detector	[13]
4	Vildagliptin	Tablet	Xterra® Waters C18 column (150mm×4.6mm, 5µm)	Ammonium Hydroxide, phosphoric acid (Aqueous Phase) & Methanol in a ratio of 60:40%v/v	210 nm	1.0 mL/min	6.3 min	UV-visible detector	[14]
5	Vildagliptin	Tablet	reversed phase C18 column (250 × 4.6 mm, 5 Hypersil Gold)	acetonitrile and water (40:60), pH adjusted to 7.0 using triethylamine	220 nm	1 ml/min	5.3 min	UV 2075 Plus Detector	[6]
6	Vildagliptin	Tablet	kromasil-C18 column [4.5 x 250 mm; 5 µm]	0.05 mmol potassium dihydrogen phosphate buffer: acetonitrile [80:20 v/v], [pH adjusted to 3.5 using orthophosphoric acid]	263nm	0.9 ml/min	2.6 min	PDA Detector	[16]
7	Vildagliptin	Tablet	Phenomenex C18 column (5µm, 250mm × 4.6mm)	Methanol: water (60:40 v/v) (pH 4.5 adjusted with OPA)	207nm	0.8 ml/min	3.58 min	-	[17]
8	Vildagliptin	Tablet	Xterra C18 column (250 mmL×4.6 mm I.D × 5µ)	acetonitrile: phosphate buffer (pH 6.0): water (65 20:15v/v/v)	239 nm	1.0 ml/min	2.32 min	Detector 2678	[18]
9	Vildagliptin	Tablet	Altima C18 column (150 mm x 4.6 mm internal diameter, 5 µm particle size)	dilute orthophosphoric acid solution, pH 2.6±0.5 as buffer, and acetonitrile (72:28 v/v)	266 nm	1.0 ml/min	3.25 min	2487 dual absorbance detector	[19]
10	Vildagliptin	Tablet	Inertsil C18 column	Acetonitrile: Phosphate Buffer (60:40) pH 3.6	215 nm	1.0 ml/min	3.924 minutes	UV-Visible detector	[20]
11	Vildagliptin	Tablet	Zorbax Eclipse Plus RP-C8 column (150 mm × 4.6 mm, 5 µm)	potassium phosphate buffer solution pH 7.0: acetonitrile (85:15, v/v)	207 nm	1.0 ml/min	5.80 min	PDA detector	[21]
12	Vildagliptin	Tablet	AthenaC18, 250 4.6mm,5 µm	(NH4)2CO32.56g/liter pH7.5-MeOH (90:10) gradient	308 nm	1.0 ml/min	12.30 min	UV-Vis wavelength detector (VWD-3400RS)	[22]
13	Vildagliptin	Tablet	XBridgeC8	acetonitrile and a solution of triethylamine 0.3% adjusted to pH 7.0 with phosphoric acid (15:85; v/v)	207 nm	1.0 ml/min	6.10 min	photodiode-array detector	[23]
14	Vildagliptin	Tablet	Xterra® Waters C18 column (150mm×4.6mm, 5µm)	1 ml of 25% ammonium hydroxide was dissolved in 1000 ml of water for chromatography, pH of the solution was adjusted to the value of 9.5 using a 50% solution of phosphoric acid and organic phase(methanol) in the ratio of 60:40 v/v	210 nm	1.0 ml/min	6.3 min	UV-visible detector	[14]
15	Vildagliptin	Tablet	Jasco Crest Pack RP C18 (250 × 4.6 mm, 5µ)	Buffer (pH 6): Acetonitrile: Methanol (70:10:20 v/v)	210 nm	1.0 mL/min	7.50 min	PDA detector	[24]
16	Vildagliptin	Tablet	Inertsil® CN-3 column (250 mm x 4.6 mm, 5 µm).	potassium dihydrogen phosphate buffer pH (4.6) - acetonitrile (15:85, v: v)	208 nm	1.0 mL/min	7.20 min	UV-visible detector	[25]
17	Vildagliptin	Tablet	Grace Cyano column (250 mm × 4.6 mm) 5 µm	25mM ammonium bicarbonate buffer and acetonitrile (65:35, v/v)	207 nm	1.2 mL/min	4.92 min	PDA detector	[26]
18	Vildagliptin (UPLC)	Tablet	Agilent C18 (4.6 ×100 mm).	Methanol: 0.1% OPA (78:22)	234 nm	1.0 mL	2.379 min	DAD detector	[27]
19	Vildagliptin	Tablet	ZORBAX Rapid Resolution HT C18 columns (150 mm x 4.6 mm)	Buffer: Acetonitrile in The ratio of 50:50 (v/v)	220 nm	1.0 ml/min	5.017 min	UV-detector	[28]
20	Vildagliptin	Tablet	Xterra C18 column (250 mmL×4.6 mm I.D × 5µ)	acetonitrile: phosphate buffer (pH 6.0): water (65: 20:15v/v/v)	239 nm	1.0 ml/min	2.32 minutes	UV-detector	[29]
21	Vildagliptin	Tablet	Water's C18 column (4.6 x 150 mm, 5 µm)	pH 8.2 buffer, acetonitrile, and methanol (50: 480:70.)	254 nm	0.5 mL/min	3.9 ± 0.1 minutes.	UV-detector	[30]

photolytic degradation, following ICH guidelines. The results showed that the method effectively separated the analytes from their degradation products, confirming its specificity [27].

Razia Sultana, et al. given a validated stability indicating RP-HPLC method for estimation of Vildagliptin. The RP-HPLC method employed a C18 column with a mobile phase of Buffer and Acetonitrile in a 50:50 (v/v) ratio, pumped at a flow rate of 1.0 mL/min. Detection was conducted at 220 nm, with a total run time of 10 minutes and a retention time for Vildagliptin of 5.017 minutes. The method was validated by ICH guidelines, demonstrating high precision and accuracy. The standard curves were linear over a concentration range of 10-60 µg/mL, with an R^2 value of 0.9996. The Limits of Detection (LOD) and Quantification (LOQ) were determined to be 0.025 µg/mL and 0.054 µg/mL, respectively. The percentage recovery of Vildagliptin from tablet formulations ranged from 98.11% to 101.16%, indicating the reliability of the method. Intra-day and inter-day precision showed % RSD values of 0.68 and 0.61, respectively, confirming the method's reproducibility [28].

The study by Sultana, et al. [29] presents a Quality by Design (QbD)-based rapid and robust RP-UHPLC method for the quantitation of vildagliptin, demonstrating its applicability in both bulk drug and pharmaceutical dosage forms. The method utilized an X-bridge C18 column with a mobile phase composed of phosphate buffer (pH 6.8) and acetonitrile in a 67:33 (v/v) ratio, achieving a flow rate of 1.0 ml/min and detection at 239 nm using a Photo-diode Array (PDA) detector. The optimization process involved a Design of Experiments (DoE) approach, which revealed that the independent variables significantly influenced the retention time, tailing factor, and theoretical plates, as confirmed by ANOVA results ($p < 0.05$). The validation of the method adhered to ICH-Q2B guidelines, showcasing excellent linearity ($R^2 = 0.9984$) across the tested concentration range (10 - 50 µg/ml), with Limits of Detection (LOD) and Quantitation (LOQ) determined at 0.01 µg/ml and 0.05 µg/ml, respectively. The method exhibited high precision, with Relative Standard Deviations (RSD) for repeatability and intermediate precision remaining below 2%. Furthermore, recovery studies indicated that the method is accurate, with recoveries ranging from 80% to 120% when spiked with standard drug substances [29].

In the study conducted by Pragati Ranjan Satpathy, et al. a robust Reverse Phase High-Performance Liquid Chromatography (RP-HPLC) method was developed and validated for the assay of Vildagliptin, in which the RP-HPLC method achieved separation of Vildagliptin within 4 minutes, with a retention time of approximately 3.9 minutes. The linearity of the method was confirmed in the concentration range of 50-90 µg/mL, with a correlation coefficient (r^2) of 0.999, indicating excellent linearity. The LOD was determined to be 2.98 µg/mL, while the LOQ was 9.94 µg/mL, demonstrating the method's sensitivity [30] (Table 1).

HPTLC method: The study by Bendale, et al. focuses on the development and validation of a stability-indicating High-performance Thin Layer Chromatography (HPTLC) method for the simultaneous determination of Vildagliptin (VIL) and Metformin Hydrochloride (MET) in pharmaceutical dosage forms. The method was rigorously validated through various stress tests, including acid and alkali hydrolysis, oxidative stress, and thermal degradation, ensuring its reliability for routine analysis in quality control settings. Results from the study include that the method exhibited excellent linearity with regression coefficients of 0.998 for MET and 0.999 for VIL, indicating high accuracy in quantification. The Limits of Detection (LOD) were determined to be 8.2 ng/band for MET and 1.74 ng/band for VIL, while the Limits of Quantitation (LOQ) were 27.06 ng/band for MET and 5.74 ng/band for VIL, demonstrating the method's sensitivity [31] (Table 2).

Liquid chromatography-mass spectrometry techniques

The article titled "Development and Validation of LC–MS/MS Method for Simultaneous Determination of Metformin and Four Gliptins in Human Plasma" presents a novel analytical method designed to quantify metformin alongside four gliptins—linagliptin, sitagliptin, and vildagliptin—in human plasma samples. Utilizing liquid chromatography tandem mass spectrometry (LC–MS/MS), the study employed a Chromolith® High Resolution RP-18e HPLC column with an isocratic elution mode. The method demonstrated high sensitivity, with limits of detection of 3.08 ng/mL, showcasing the method's sensitivity. The validation study demonstrated high precision and accuracy, with %CV and %RE values generally below 1% for most data points. A linear calibration curve was established, with a correlation coefficient exceeding 0.999. The method proved effective for monitoring plasma levels in pharmacokinetic studies, confirming vildagliptin's stability in human plasma during the analysis [32].

The article presents an LC-MS/MS method for quantifying Vildagliptin in rat plasma, validated for use in pharmacokinetic studies. The method demonstrated excellent linearity (1.57 to 501.21 ng/mL), with high precision, accuracy, and recovery rates, complying with FDA guidelines. Stability tests confirmed the drug's reliability under different conditions [33] (Table 3).

Gas chromatography

The research article presents a new gas chromatographic method for the simultaneous quantification of Metformin hydrochloride and Vildagliptin in bulk and pharmaceutical dosage forms. Utilizing a Gs-Tek INNOWAX column, the method employed a Flame Ionization Detector with optimal conditions including a 1 µL injection volume and a nitrogen carrier gas flow rate of 1 mL/min. The initial oven temperature was set at 100 °C, increasing to 300 °C at a rate of 10 °C per minute. Key results showed retention times of 10.203 minutes for Metformin and 22.021 minutes for Vildagliptin. Validation

Table 2

Sr. No.	Drug	Matrix/ Dosage Form	Stationary Phase	Mobile Phase	Detection	Rf	Linearity Range	Ref. No.
1.	Vildagliptin	Tablets	silica gel precoated aluminum plate 60 F254, [(20 × 10 cm) with 250 µm thickness; E. Merck	Hexane: Methanol: Acetonitrile: Glacial Acetic Acid in the ratio of 2:3.5:2.5:0.2 (v/v/v/v)	217 nm.	0.73 ± 0.02	**10-150 ng/band**.	[23]

Table 3

Sr. No.	Drug	Matrix/ Dosage form	Stationary Phase	Mobile Phase	Flow Rate (ml/min)	Ret. Time (min.)	Ref. No.
1	Vildagliptin	Human Plasma	High Resolution RP-18e HPLC column (100 mm × 4.6 mm, macropores 1.15 µm)	0.01 M ammonium formate buffer (pH 3.0): acetonitrile (80:20 v/v)	0.4 mL/min	4.097 min	[32]
2	Vildagliptin	Rat Plasma	C18 column (50 mm × 4.6 ID, 5 µ)	ACN: 2 mM AA buffer at pH 3.4 (90:10 % v/v)	0.350 mL/min	1.68 min	[33]

studies indicated excellent linearity, with recovery values of 100.31% for Metformin and 100.33% for Vildagliptin, both with low relative standard deviations (% R.S.D.). All validation parameters met ICH guidelines, confirming the method's reliability for routine analysis. This study establishes an effective analytical approach for detecting these antidiabetic medications in various formulations [34].

Uçaktürk E, et al. reported a study that presents a novel and efficient Gas Chromatography-Mass Spectrometry (GC-MS) method for the sensitive and specific analysis of Vildagliptin (VIL) in pharmaceutical formulations. The method involves a simple one-step derivatization process using MSTFA/NH_4I/-mercaptoethanol, which significantly enhances the thermal stability and volatility of VIL, allowing for effective detection. The validation of the method demonstrated a Limit of Detection (LOD) of 1.5 ng mL^{-1} and a Limit of Quantitation (LOQ) of 3.5 ng mL^{-1}, with a linear range of 3.5-300 ng mL^{-1} and high precision and accuracy values (intra- and interday precision ≤ 3.62% and accuracy ranging from -0.26% to 2.06 % [35] (Table 4).

Capillary electrophoresis techniques

A stability-indicating Capillary Zone Electrophoresis (CZE) method was validated for the determination of Vildagliptin (VLG) in pharmaceutical dosage forms using Ranitidine Hydrochloride (RH) as an internal standard. The CZE method was carried out in a fused silica capillary (64.5 cm total length and 56.0 cm effective length, 50 µm i.d.) by applying a potential of 25 kV (positive polarity), hydrodynamic injection by 50 mbar for 5 s, and the temperature of the capillary cartridge was 25 ◦C. The selected Background Electrolyte (BGE) consisted of 25mM potassium phosphate (pH 8.0) with UV/ PDA detection at 207 nm. The electrophoretic separation was obtained within 6 min and was linear in the range of 50–200 g/mL (r = 0.9994) [36].

The objective of the present work was to establish a rapid, sensitive, and validated capillary electrophoresis Quadrupole Time-of-flight Mass Spectrometry method from rat plasma. Vildagliptin was estimated in rat plasma after precipitation of plasma proteins by acetonitrile, using sitagliptin as an internal standard. For the separation of vildagliptin from plasma components, a fused silica capillary with background electrolyte consisting of 0.25 mM ammonium formate buffer, with SL composition of 50:50 methanol and water consisting of 0.25% formic acid, pumped at a flow rate of 0.2 ml/min, was used. The detection limit of the method was found to be 0.31 ng/ml, and the percent assay was above 93%. The percent coefficient of variations for both intraday and interday were less than 9% [37] (Table 5).

UV-visible spectrophotometric overview

UV-visible spectroscopy overview: The present study was undertaken to develop a spectrophotometric method for the determination of vildagliptin in pharmaceutical dosage forms. This paper describes a simple, rapid, accurate, and precise UV-Spectrophotometric method for the assay of vildagliptin and linagliptin in bulk and marketed tablet dosage forms. The validation of the developed method was carried out according to ICH guidelines with respect to linearity, precision, accuracy, specificity, limit of detection, and limit of quantification. Calibration curves were obtained in the concentration range of 8-32 µg/ml for vildagliptin and 5-25 µg/ml for linagliptin with good correlation coefficients (r = 0.999). 0.734 µg/ml was the LOD, and 2.224 µg/ml was the LOQ, respectively [38].

A simple, accurate, precise, and reproducible method has been developed for the simultaneous estimation of Vildagliptin and Metformin hydrochloride in combined tablet dosage forms. The estimation was done by multi-wavelength technique, at wavelengths of 217 nm and 234 nm over the concentration ranges of 0.7µg/ml and 7 µg/ml, with a mean recovery 100% for both drugs, Vildagliptin and Metformin hydrochloride, respectively. The results of the analysis were validated statistically, and recovery studies were carried out as per ICH guidelines. LOD and LOQ were found to be 0.023 µg / ml and 0.225 µg / ml [39].

A simple, accurate, precise, cost-effective, rapid, and sensitive UV/visible spectrophotometric method was developed for the determination of Vildagliptin in active pharmaceutical dosage form. The developed method was

Table 4

Drug	Matrix/ Dosage form	Stationary Phase	Carrier gas	Flow Rate (ml/min)	Ret. Time (min.)	Ref. No.	
Vildagliptin	Tablet	Gs-Tek INNOWAX column, which has a 30 m length, 0.25 mm I.D., and 1.8 µm df	nitrogen	1 mL/min	22.021 min	[34]	
Vildagliptin	Tablet	5% phenyl methylpolysiloxane capillary column (30 m × 0.25 mm i.d. with 0.25 μm film thickness, Agilent Technologies	-	1 mL/min	-	[35]	

Table 5

Sr.No.	Drug	Dosage Type	Detection (nm)	Capillaries	Separation Voltage	Temp/Pressure	Ref. No.
1	Vildagliptin	Tablet	207 nm	Fused silica capillary (64.5cm total length and 56.0 cm effective length, 50 µm i.d.)	+25kV	50 mbar for 5s at 25 °C	[36]
2	Vildagliptin	Rat Plasma	207 nm	fused silica capillary (Agilent Technologies, Germany) having a 50 µm internal diameter with an effective total capillary length of 75 cm to the MS detector.	+25kV	50 mbar for 10s at 200 °C	[37]

validated as per ICH guidelines. The solvents used were water, 0.1 N HCl, and phosphate buffer pH 7.4, and the wavelength corresponding to maximum absorbance of the drug was found at 210 nm. The linear response for the concentration range of 2-12 µg/ml of vildagliptin for water, 0.1 N HCl, and phosphate buffer pH 7.4 was recorded, each with a regression coefficient R2 = 0.9998, 0.9994, and 0.9991, respectively [40].

Tekkeli SE presents three rapid and sensitive spectrophotometric methods for determining Vildagliptin (VLD) in pharmaceuticals, utilizing Charge Transfer (CT) complexes with Chloranilic Acid (CA), tetrachloro-1,4-benzoquinone (p-chloranil), and 7,7,8,8-Tetracyanoquinodimethane (TCNQ). Spectrophotometric quantification of the colored products was performed at specific wavelengths: 520 nm for CA, 535 nm for p-chloranil, and 842 nm for TCNQ. The methods adhered to Beer's law within concentration ranges of 20-250 µg/mL for CA, 25-400 µg/mL for p-chloranil, and 20-500 µg/mL for TCNQ. Validation of the methods confirmed their specificity, accuracy, and precision, with successful application in pharmaceutical preparations showing no interference from common excipients [41].

Conclusion

Vildagliptin in pharmaceutical formulations can be analyzed using a variety of procedures. The analysis of published data revealed that Vildagliptin was regularly measured in various pharmaceutical dosage forms, such as tablets, using HPLC methods. HPLC with UV detection is useful because it provides exact results at a lower cost than more advanced detection techniques. This review summarizes the most advanced analytical approaches available for identifying Vildagliptin. Thanks to the review, analytical chemists will profit from understanding the essential solvents and their combinations for the tools available in the analytical laboratory. The most efficient collection of parameters should reduce both the time and expense of the investigation. The most effective collection of parameters should reduce both the time and expense of the study while producing reliable analytical results. The strategies are also useful for choosing parameters for in-process analysis when creating an API.

References

1. He YL. Clinical pharmacokinetics and pharmacodynamics of vildagliptin. Clin Pharmacokinet. 2012;51:147-62. Available from: https://doi.org/10.2165/11598080-000000000-00000
2. Henness S, Keam SJ. Vildagliptin. Drugs. 2006 Oct;66:1989-2001. Available from: https://doi.org/10.2165/00003495-200666150-00007
3. Lauster CD, McKaveney TP, Muench SV. Vildagliptin: a novel oral therapy for type 2 diabetes mellitus. Am J Health Syst Pharm. 2007 Jun 15;64(12):1265-73. Available from: https://doi.org/10.2146/ajhp060564
4. Vildagliptin package insert. Available from: https://www.geneesmiddeleninformatiebank.nl/pars/h124950.pdf
5. Croxtall JD, Keam SJ. Vildagliptin: a review of its use in the management of type 2 diabetes mellitus. Drugs. 2008 Nov;68:2387-409. Available from: https://doi.org/10.2165/0003495-200868160-00009
6. He H, Tran P, Yin H, Smith H, Batard Y, Wang L, et al. Absorption, metabolism, and excretion of [14C] vildagliptin, a novel dipeptidyl peptidase 4 inhibitor, in humans. Drug Metab Dispos. 2009 Mar 1;37(3):536-44. Available from: https://doi.org/10.1124/dmd.108.023010
7. Vildagliptin: Uses, Interactions, Mechanism of Action – DrugBank.. Available from: https://go.drugbank.com/drugs/DB04876
8. Alok Pote, Santhanam Ravisankar, Ganesh Sangle, Sunil Agarwal, Mohan Patil, Nitin Deshmukh, et al.Clinical pharmacokinetics and pharmacodynamics of vildagliptin 50 mg sustained release tablet formulation in healthy Indian males after single and multiple-dose. Int J Res Med Sci. 2021;9:510-517. Available from: https://doi.org/10.18203/2320-6012.ijrms20210433
9. He YL, Serra D, Wang Y, Campestrini J, Riviere GJ, Deacon CF, et al. Pharmacokinetics and pharmacodynamics of vildagliptin in patients with type 2 diabetes mellitus. Clin Pharmacokinet. 2007;46(7):577-88. Available from: https://doi.org/10.2165/00003088-200746070-00003
10. Serra YL. Pharmacokinetics and Pharmacodynamics of Vildagliptin in Patients with Type 2 Diabetes Mellitus. Semantics Scholar. Available from: https://www.semanticscholar.org/paper/Pharmacokinetics-and-Pharmacodynamics-of-Vildagliptin-Serra/
11. Boovizhikannan T, Palanirajan VK. RP-HPLC determination of vildagliptin in pure and in tablet formulation. J Pharm Res. 2013;7(1):113-6. Available from: https://doi.org/10.1016/j.jopr.2013.01.001
12. Kashid AM, Ghorpade DA, Toranmal PP, Dhawale SC. Development and validation of a reversed-phase HPLC method for the determination of vildagliptin using an experimental design. J Anal Chem. 2015;70:510-5. Available from: http://dx.doi.org/10.1134/S1061934815040061

13. Sujeetkumar A, Sandhya A, Patil PR, Akshata J, Archana C. Development of RP-HPLC Method for Vildagliptin in Pharmaceutical Dosage Form. Int J Pharm Sci Rev Res. 2023;78(1):36-40. Article No. 06. Available from: https://globalresearchonline.net/ijpsrr/v78-1/06.pdf

14. Malakar A, Bokshi B, Nasrin D. Development and validation of RP-HPLC method for estimation of vildagliptin from tablet dosage form. Int J Pharm Life Sci. 2012;1(1). Available from: https://doi.org/10.3329/ijpls.v1i1.12947

15. Dhale C, Janhavi RR. Stability Indicating HPLC MS method for determination of degradation products in Vildagliptin. J Anal Bioanal Tech. 2019;10:1-5. Available from: https://www.researchgate.net/publication/354066375_Stability_Indicating_HPLC_MS_Method_for_Determination_of_Degradation_Products_in_Vildagliptin

16. Jayaprakash R, Natesan SK, Lalitha K. Stability indicating RP-HPLC method development and validation for the simultaneous determination of vildagliptin and metformin in pharmaceutical dosage form. Int J Pharm Pharm Sci. 2017;9(3):150-7. Available from: https://core.ac.uk/download/pdf/482240668.pdf

17. Raosaheb JR, Dabhade MP, Vikram KS, Sanjay SV, Chand SW. RP-HPLC method development and validation of vildagliptin in bulk and dosage form. World J Pharm Pharm Sci. 2017;6(9):1161-76. Available from: http://dx.doi.org/10.20959/wjpps20179-9980

18. Dayyih WA, Hamad M, Mallah E, Dayyih AA, Awad R, Zakaria Z, et al. METHOD Development and Validation of Vildagliptin and Metformin HCl in Pharmaceutical Dosage form by Reversed Phase-High Performance Liquid Chromatography (RP-HPLC). Int J Pharm Sci Res. 2018;9(7):2965-72. Available from: https://www.researchgate.net/publication/328407528_Method_Development_And_Validation_of_Vildagliptin_and_Metformin_HCL_in_Pharmaceutical_Dosage_Form_by_Reversed_Phase-High_Performance_Liquid_Chromatography_RP-HPLC

19. Rao KH, Rao AL, Sekhar KB. DEVELOPMENT AND VALIDATION OF HPLC METHOD FOR THE ESTIMATION OF VILDAGLIPTIN IN PHARMACEUTICAL DOSAGE FORM. Int J Pharm Chem Biol Sci. 2014;4(2):361-366. Available from: https://www.ijpcbs.com/articles/development-and-validation-of-hplc-method-for-theestimation-of-vildagliptin-in-pharmaceutical-dosage-form.pdf

20. Deshmukh SB, Jadhao UT, Patil JA, Thoke ST. Analytical method development and validation of vildagliptin in bulk drug and its pharmaceutical dosage form by RP-HPLC. Int J Res Publ Rev. 2024:3350-3357. Available from: https://ijrpr.com/uploads/V5ISSUE4/IJRPR25059.pdf

21. Barden AT, Piccoli BL, Volpato NM, Steppe M. Second-order derivative UV spectrophotometric and RP-HPLC methods for the analysis of vildagliptin and application for dissolution study. Drug Anal Res. 2018;2(1):46-53. Available from: http://dx.doi.org/10.22456/2527-2616.86511

22. Al-Qudah E, Arar S, Sweidan K. Forced degradation studies of vildagliptin raw material alone and in the presence of excipients using HPLC-UV analysis. J Excipients Food Chem. 2020;11(2):29-41. Available from: https://jefc.scholasticahq.com/article/13503-forced-degradation-studies-of-vildagliptin-raw-material-alone-and-in-the-presence-of-excipients-using-hplc-uv-analysis

23. Barden AT, Salamon B, Schapoval EE, Steppe M. Stability-indicating RP-LC method for the determination of vildagliptin and mass spectrometry detection for a main degradation product. J Chromatogr Sci. 2012;50(5):426-32. Available from: https://doi.org/10.1093/chromsci/bms024

24. Chaphekar MM, Hamrapurkar PD. Development and validation of RP-HPLC assay method for vildagliptin using QbD approach and its application to forced degradation studies. Int J Pharm Sci Drug Res. 2016;8:157-65. Available from: http://dx.doi.org/10.25004/IJPSDR.2016.080306

25. Mohammad MA, Elkady EF, Fouad MA. Development and validation of a reversed-phase column liquid chromatographic method for the simultaneous determination of two novel gliptins in their binary mixtures with metformin. Eur J Chem. 2012;3(2):152-5. Available from: https://doi.org/10.5155/eurjchem.3.2.152-155.570

26. Satheeshkumar N, Pradeepkumar M, Shanthikumar S, Rao VJ. Development of a validated stability-indicating assay method for simultaneous estimation of metformin hydrochloride and vildagliptin by RP-HPLC. Drug Res (Stuttg). 2014;64(03):124-9. Available from: https://doi.org/10.1055/s-0033-1354373

27. Galande VV, Kolhe MH, Khatal AR, Bhor RJ, Gawali PS, Bhalerao PS, et al. Stability Indicating Method Development and Validation of Vildagliptin and Dapagliflozin in Bulk and Marketed Formulation by UHPLC Method. Int J Pharm Investig. 2024;14(3):1599-1603. Available from: http://dx.doi.org/10.25258/ijddt.14.3.49

28. Sultana R, Bachar SC, Rahman F. Development and validation of stability indicating assay method of vildagliptin in bulk and tablet dosage form by RP-HPLC. Int J Pharm Life Sci. 2013;4(4):2530-4. Available from: https://www.researchgate.net/publication/263085943_Development_and_validation_of_stability_indicating_assay_method_of_vildagliptin_in_bulk_and_tablet_dosage_form_by_RP-HPLC

29. Sultana S, Kumar U, Hossain MS, Lira DN, Rouf AS. QbD approach for the development and validation of RP-UHPLC method for quantitation of vildagliptin. Dhaka Univ J Pharm Sci. 2017;16(1):107-17. Available from: https://doi.org/10.3329/dujps.v16i1.33388

30. Satpathy PR, Goud VM, Bhagya B, Sharma JV, Shyamala N. Development and validation of an RP-HPLC method for the assay of vildagliptin. World J Pharm Pharm Sci. 2014;3(2):2303-10. Available from: https://www.researchgate.net/profile/Mohan-Goud/publication/260788523_Development_and_validation_of_RP-HPLC_method_for_the_assay_of_vildagliptin/links/0deec53234bf790563000000/Development-and-validation-of-RP-HPLC-method-for-the-assay-of-vildagliptin.pdf

31. Bendale AR, Singh RP, Vidyasagar G. Development and validation of stability-indicating HPTLC method for determination of vildagliptin and metformin hydrochloride in the pharmaceutical dosage forms. Int J Appl Pharm. 2018;10(1):36-45. Available from: http://dx.doi.org/10.22159/ijap.2018v10i1.20555

32. Al Bratty M, Alhazmi HA, Javed SA, Lalitha KG, Asmari M, Wölker J, et al. Development and validation of–LC-MS/MS method for simultaneous determination of metformin and four gliptins in human plasma. Chromatographia. 2017;80:891-9. Available from: https://link.springer.com/article/10.1007/s10337-017-3288-0

33. Sakthimanigandan K, Ganesh M, Kanthikiran V, Sivakumar T, Jang H. Liquid chromatography tandem mass spectrometry (LC-MS/MS) method for the determination of Vildagliptin in rat plasma. Acta Chromatogr. 2015;27(2):295-307. Available from: https://doi.org/10.1556/achrom.27.2015.2.7

34. Mohite P, Bhusal R, Khandre Y, Pandhare R, Pawar A. A new gas chromatographic method for quantification of Metformin hydrochloride and Vildagliptin in bulk and pharmaceutical dosage form: development and validation. Future J Pharm Sci. 2024;10(1):62. Available from: https://link.springer.com/article/10.1186/s43094-024-00635-z

35. Uçaktürk E. Development of Sensitive and Specific Analysis of Vildagliptin in Pharmaceutical Formulation by Gas Chromatography Mass Spectrometry. J Anal Methods Chem. 2015;2015(1):707414. Available from: https://doi.org/10.1155/2015/707414

36. Barden AT, Piccoli BL, Volpato NM, Schapoval EE, Steppe M. Capillary zone electrophoresis for determination of vildagliptin (a DPP-4 inhibitor) in pharmaceutical formulation and comparative study with HPLC. Pharmazie. 2014;69(2):86-91. Available from: https://doi.org/10.1691/ph.2014.3123

37. Attimarad M, Nagaraja SH, Aldhubiab BE, Nair AB, Venugopala KN. Determination of vildagliptin in rat plasma by capillary electrophoresis tandem mass spectrometry: Its application to pharmacokinetic study. Indian J Pharma Edu Res. 2017;51:636-43. Available from: https://pdfs.semanticscholar.org/2168/574154f236935ead1937ff97872c7001746e.pdf

38. Banik S, Karmakar P, Miah MA. Development and validation of a UV-spectrophotometric method for the determination of vildagliptin and linagliptin in bulk and pharmaceutical dosage forms. Bangladesh Pharm J. 2015;18(2):163-8. Available from: https://doi.org/10.3329/bpj.v18i2.24316

39. Gundala U, Bhuvanagiri CS, Nayakanti D. Simultaneous estimation of vildagliptin and metformin in bulk and pharmaceutical formulations by UV spectrophotometry. Am J PharmTech Res. 2013;3(1):338-45. Available from: https://www.researchgate.net/publication/250612476_Simultaneous_Estimation_of_Vildagliptin_and_Metformin_in_Bulk_and_Pharmaceutical_Formulations_by_UV_Spectrophotometry

40. Mane SV, Khan MA. Development of UV-Visible spectrophotometric method for the estimation of vildagliptin in different media. J Pharm Biol Sci. 2022;10(2):83-7. Available from: http://dx.doi.org/10.18231/j.jpbs.2022.016

41. Tekkeli SE, Bahadori FA. Development and validation of spectrophotometric methods for the determination and spectroscopic characterization of vildagliptin using Il-acceptors in pharmaceutical preparations. J Chil Chem Soc. 2014;59(4):2705-9. Available from: http://dx.doi.org/10.4067/S0717-97072014000400016