A Validated Chiral Liquid Chromatographic Method for the Enantiomeric Separation of Lacosamide Drug Product and its Dosage Forms

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Abstract

A new and simple, rapid, selective isocratic normal phase liquid chromatographic (NP-LC) method was developed for the chiral purity of Lacosamide ((R)-2-acetamido-N-benzyl-3- methoxypropionamide) and its undesired S-enantiomer ((S)-2-acetamido-N-benzyl-3-methoxypropionamide). Superior resolution between Lacosamide and its S-enantiomer was achieved on Cellulose tris (3,5-Dichlorophenylcarbamate) immobilisation of polysaccharide derivatives based Chiralpak IC (25 mm × 4.6 mm, 5 µm) column using n-hexane : ethanol (85:15, v/v) as a mobile phase at 27°C column oven temperature. The USP resolution between the enantiomers was found more than five. Mobile phase flow was fixed at a rate of 1.0 mL/min and elution was monitored at 210 nm. The test concentration was 1000 µg/ml, Limit of detection and quantitative of S-enantiomer is 0.17 µg/mL and 0.48 µg/mL respectively. The percentage RSD of the peak area of six replicate injections of S-enantiomer at LOQ concentration was 5.8. The percentage recoveries of S-enantiomer from Lacosamide (LAC) were ranged from 105%-107%. The test solution and mobile phase were observed to be stable up to 48 h on bench top. The method was found to be selective, precise, linear, accurate and also robust. This method was successfully validated according to the International Conference Harmonization (ICH) guidelines.

Keywords: Lacosamide; Enantiomers; Chiral liquid chromatography; Validation; Specificity

Introduction

Epilepsy is a major neurological disorder that affects all populations [1]. Epilepsy describes the types of recurrent seizures produced by paroxysmal excessive neuronal disorders in the brain [2-3]. The mainstay of treatment has been the long-term and consistent administration of anticonvulsant drugs [4-6]. Unfortunately, current medications are ineffective for approximately one-third of patients with epilepsy [7]. Many people continue to have seizures, while others experience disturbing side effects (e.g., drowsiness, dizziness, nausea, liver damage) [8]. The lead compound, (R)-lacosamide ((R)-2, (R)-N-benzyl 2-acetamido-3-methoxypropionamide, has recently gained regulatory approval for adjunctive therapy for partial-onset seizures in adults [9].

The biological activities of chiral substances often depend upon their stereochemistry, thus, showing significant enantioselective differences in pharmacokinetics and pharmacodynamics. There is a growing demand for the direct methods of enantiomeric separation of chiral drugs, as the US food and Drug Administration (USFDA) has issued an order to specify the enantiomeric purities of chiral drugs [10].

Enantiomeric separations have acquired importance in all stages of drug development and commercialization process. Therefore, the development of new methods for efficient chiral separations mainly based on HPLC, capillary electrophoresis (CE) or gas chromatography (GC) is more necessary [11,12]. The chromatographic separation of enantiomers using high-performance liquid chromatography (HPLC) with chiral stationary phases (CSPs) is one of the most useful and popular techniques for enantio-purity analysis in pharmaceutical preparations and biological fluids [13].

The thorough literature survey revealed that none of the most recognized pharmacopoeias or any journals including this drug for the determination chiral purity is not available on the enantiomeric separation of LAC drug substance (Figures 1A and 1B) and its penultimate stages by HPLC on the analytical method or any analytical tools. The chiral purity of drug is very important since only R-isomer of it is active and S-isomer is inactive. The aim of this study was to develop a simple HPLC method capable to separate an enantiomer of the title compound. Our research aimed to evaluate the enantiomeric resolving capability of the immobilized-type Chiralpak IC CSP in the polar organic phase and normal-phase conditions. First, we selected a mobile phase capable of giving a baseline separation of LAC. The best analytical normal-phase condition was validated in terms of linearity, precision, accuracy, repeatability, ruggedness and robustness and limits of detection (LOD) and limit of quantification (LOQ) in order to quantify both enantiomers in active pharmaceutical ingredient and its drug dosage formulations.

This method can be able to separate all process impurities and degradants. It can also be able to separate its intermediate stages (penultimate stage) enantiomers. This method could be useful for reaction monitoring for synthesis of Lacosamide and its dosage forms. This method can be used for the routine regular analysis as well as the stability studies.

Experimental

Chemicals and reagents

N-Hexane was purchased from Merck (Worli, Mumbai, India), and Ethanol of AR grade (purity 99.9%) from Ching chaung Chemical, China. All the chemicals were used without further purification.

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Apparatus

The liquid chromatography systems Waters alliance 2695 separation module with 2998 diode array detector (DAD) and Agilent (Wilmington, Delaware, USA) 1100 system equipped with photo DAD and a variable wavelength detector (VWD), were used for method development and method validations. The output signal was monitored and processed by using Waters (Milford, MA, USA) Empower-2 software. Chiralpak-IC (250 mm × 4.6 mm, 5 μm), Immobilized cellulose tris 3,5 dichlorophenylcarbamate, coated on 5 μm silica-gel support, was purchased from Daicel Chemical Industries (Tokyo, Japan).

Chromatographic conditions

Enantioseparation was achieved on a Chiralpack-IC column (250 mm × 4.6 mm, 5 μm) by using the mobile phase consisting of n-hexane: ethanol (85:15, v/v), delivered at a flow rate of 1.0 mL/min. The column oven temperature was maintained at 27°C and the wavelength was monitored at 210 nm. The injection volume was 10 μL. 2-Propanol (IPA) was used as diluent.

Preparation of test solution and control solution

Stock solutions of (R)-LAC, (S)-LAC, (R)-LAC-1 and (S)-LAC-1 (1000 μg/mL) were prepared individually by dissolving the appropriate amount in IPA and filled to the mark with IPA, and further diluting to required concentration with IPA.

Commercially available tablets containing 5 mg of LAC (Vimpact) (n=10) were pulverized with a pestle in a porcelain mortar. The tablet powder was taken into a 100 mL of volumetric flask, made up to the mark with IPA and the suspension was sonicated for 10-12 min and filtered through 0.45 μm membrane filters. The IPA solution was injected to LC system.

Weight percentage of each enantiomer (R, S) present in the sample was calculated by area normalization method because the other isomer was having the same response to that of R-LAC.

Method validation

The method was validated (in terms of sensitivity, linearity, accuracy, precision, solution stability, mobile phase stability, and robustness) in accordance with International Conference Harmonization (ICH) guidelines.

Specificity/Selectivity: The specificity/selectivity of the developed LC method was determined in the presence of its related impurities (Figure 1C and 1D), LAC enantiomers and degradation products. Forced degradation studies were also performed on LAC bulk drug samples to provide an indication of the stability-indicating property and specificity of the proposed method. The stress conditions employed for degradation study included light (1.2 million lx h/m²/240 h), heat (90°C/10 days), humidity (40°C/75% RH/10 days), acid hydrolysis (0.1 M HCl/10 mL/3 h at 70°C), base hydrolysis (0.025 M NaOH/10 mL/90 min at RT), and peroxide degradation (6% H_2O_2/10 mL /9 h at 70°C). About 5%-15% degradation was observed in forced degradation studies. The typical chromatograms of control sample and stressed samples are represented in Figures 2A-2C. Peak purity of stressed sample of R-LAC was checked by using photo diode array detector (DAD/PDA). Purity angle was found less than purity threshold in all stress samples and no interference was found from blank demonstrating the analyte peak homogeneity.

**LOD and LOQ:** LOD and LOQ represent the concentration of the analyte that would yield a signal/noise ratio (S/N) of 3 and 10, respectively. LOD and LOQ of (S)-LAC, (R)-LAC were determined by injecting a series of diluted solutions.

Precision and repeatability: Method precision was determined by measuring the repeatability (intra-day precision) and intermediate precision (inter-day precision) of retention times and peak areas for LAC enantiomers. The intra-day variability was performed by the
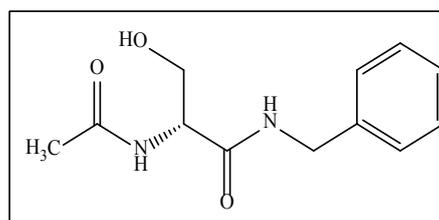
1A: LAC: (R)-2-acetamido-N-benzyl-3-methoxypropanamide.
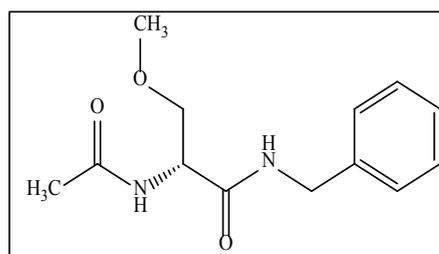
1B: LAC:(S)-2-acetamido-N-benzyl-3-methoxypropanamide.
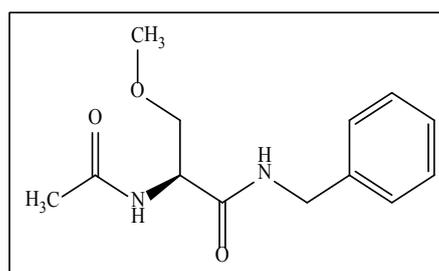
1C: (R)-Imp-1: (R)-2-acetamido-N-benzyl-3-hydroxypropanamide.

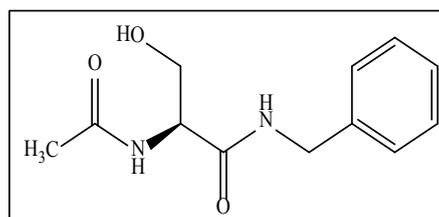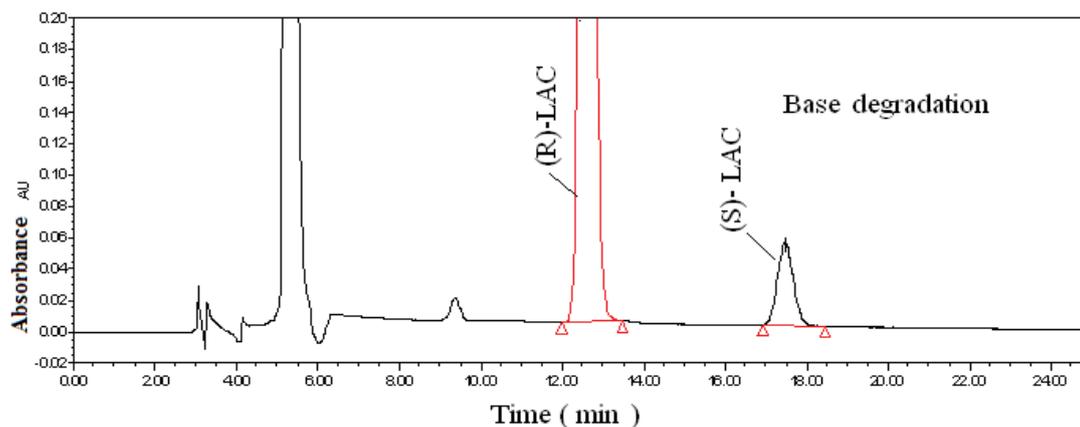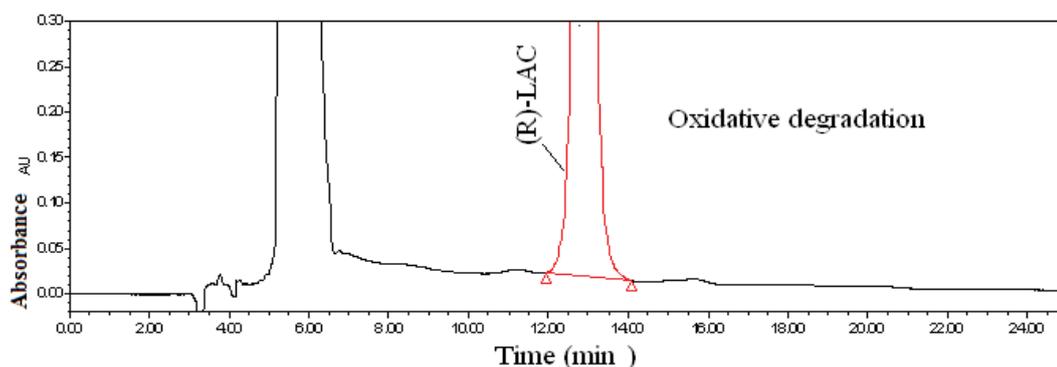1D: (S)-Imp-1: (S)-2-acetamido-N-benzyl-3-hydroxypropanamide.

Figure 1: Lacosamide (LAC) and its impurities structures.

2A: Base degradation chromatogram.

2B: Oxidative degradation chromatogram

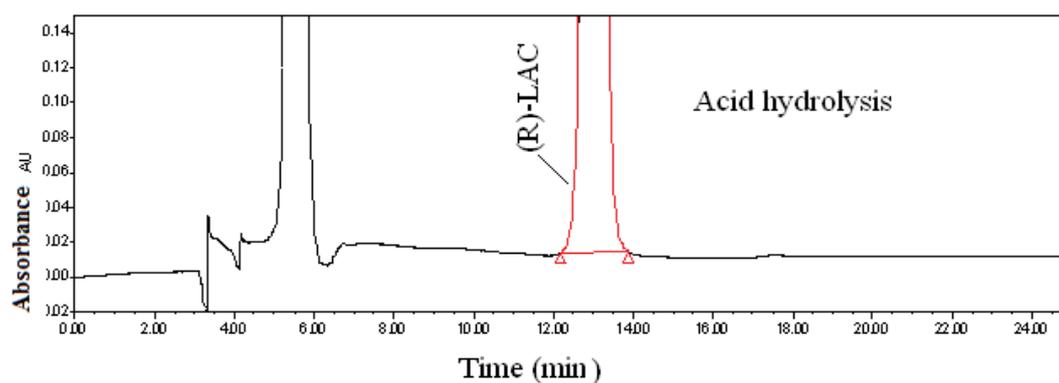2C: Acid degradation chromatogram

Figure 2: The degradation/specificity chromatograms of LAC.

same analyst over one day, while inter-day precision was carried out by another independent analyst over three days. In order to determine the repeatability of the method, replicate injections (*n*=6) of 1.5 µg/mL of LAC enantiomers were carried out. The intermediate precision was evaluated over three days by performing six consecutive injections each day. Precision was reported as % of relative standard deviation (%RSD).

Linearity: The linearity evaluation was performed with the spiked standard solutions of (S)-enantiomer at the concentrations ranging

from six concentration (n=6) levels from LOQ to 150% (LOQ, 50, 75, 100, 125 and 150%). Three injections (n=3) of each solution were made under the chromatographic conditions described above, using an injection volume of 10 µL. The calibration curve was drawn by plotting the peak areas of (S)-LAC and (R)-LAC against its corresponding concentration. The %RSD and Y-intercept of the calibration curve (linear regression equation) were computed.

Accuracy: Standard addition and recovery experiments were conducted to determine accuracy of other enantiomer method for

quantification of the impurities in bulk drug samples and dosage forms. The study was carried out in triplicate at 0.375, 0.75 and 1.125 µg/mL concentrations, whereas the analyte concentration was 1000 µg/mL. The percentage recoveries of (S) and (R)-LAC were calculated.

Solution stability and mobile phase stability: The solution stability of LAC and its enantiomers in this method was carried out by leaving spiked sample solution in tightly capped volumetric flask at room temperature (bench top) for 48 h. Contents of other enatiomer were determined for every 6 h interval. Mobile phase was also carried out for 48 h by injecting the freshly prepared sample solutions for every 6 h interval. Contents of other enatiomer were checked in the test solutions. Mobile phase prepared was kept constant during the study period.

Robustness: To determine the robustness of the developed method, the chromatographic conditions were deliberately altered and verified including the system suitability criteria. Establish the selectivity factor in all the robustness studies for enantiomer impurity and compare with regular experiment. The flow rate of mobile phase was 1.0 mL/min, to study the effect of flow rate on the peak USP tailing and USP resolution between enantiomers, flow rate was altered by 0.2 units, i.e, from 0.8 to 1.2 mL/min. The effect of composition of ethanol ratio on peak USP resolution and tailing of LAC were studied by varying ± 10% ethanol solvent. The effect of column temperature was studied at 27°C ± 5°C (22°C, 27°C and 32°C).

Results

Method development

The aim of this work was to separate the enantiomers for the accurate quantification of (S)-enantiomer. Racemic mixture solution of 1 mg/mL prepared in IPA was used in the method development. To develop a rugged and suitable LC method for the separation of LAC enantiomers, different mobile phases and stationary phases were employed. Initial development trials were carried out on the chiralpak AD-H column with the mobile phase combination of n-hexane and ethanol in the ratio of 90:10 (v/v). The peaks were retained very early and selectivity could be very poor. With further increasing the ratio of ethanol by ten percent volume, selectivity was remains same, but the peak shape was broad with tailing. After that introduced chiralcel OD-H and chiralpak-AS columns with different combinations of mobile phases but individual pair resolutions were observed with tailing but the selectivity was poor (Figure 3A and 3B), with merged (S)-LAC and (S)-Imp-1 peaks. Apply above mobile phase combination to phenominex Lux Cellulose-2 column and get individual separation for each enatiomers, but (R)-LAC and (R)–Imp-1 were merged Figures 3C and 3D. Finally introduce chiralpak-IC immobilized stationary phase initially with n-hexane and ethanol in the ratio of 50:50 (v/v), (R)-LAC and (S)-Imp-1 were not separated well (Figure 3E). Changing in mobile phase ratio with n-Hexane: Ethanol (7:3, v/v) (R)-LAC and (S)-Imp-1 completely merged (Figure 3F), trial with a mobile phase n-Hexane: Ethanol (9:1, v/v) combination achieved best enantiometric separation (Figure 3G). But retention time was high. Reducing the retention time by increasing ethanol 5% in the mobile phase combination, which is 85:15 (v/v) ratio of n-hexane and ethanol, eventually reduced retention time without compromising and affects on USP resolution (Rs > 3.0) with all pairs of enantiomers. In the optimized method, retention times of (R)-LAC, (S)-LAC and (R)-Imp-1 and (S)-Imp-1 its enantiomer were about 11.5 and 15.8 min; 9.5 and 12.1 respectively (Figure 3H).

However other verified mobile phase ratio combinations like 2-Propanol and Butanol, column oven temperature was also studied at room temperature 22°C and 40°C. In view of possible interference study, attempts were also made by adjusting the mobile phase flow rate to separate all process related impurities. But no significant impact was observed on the critical chromatographic parameters (resolution, USP tailing and retention time).

Influence of the mobile phase composition on enantioselectivity and resolution

Besides the already available Chiralpak IA, Chiralpak IB and Chiralpak IC CSPs, a new immobilised-type CSP for HPLC, the Chiralpak IC CSP, has been recently launched by Daicel Chemical Industries Ltd. The Chiralpak IC used cellulose tris (3,5- dichlorophenylcarbamate) immobilised onto silica 5 micron particles as a chiral selector. In the first part of our study, the resolving ability of the Chiralpak IC CSP towards LAC was investigated in the nonpolar organic mode using pure n-Hexane, n-Hexane and Ethanol with a ratio of 85:15 (v/v). The resolving power of the IC CSP was sufficiently high to achieve a baseline enantioseparation in each of the used conditions. The best resolution value was achieved by using the n-Hexane and Ethanol with a ratio of 85:15 (v/v) eluent with enantioselectivity factor (k) and resolution factor (Rs) values of 1.3 and 5.7, respectively (Figure 3I).

Chemoselective analysis

A critical aspect in the development of an analytical method to determine the enantiomeric purity of a chiral drug is the presence of impurities from the processes of synthesis, degradation or manufacturing either in the drug substance or in the finished product. The main organic impurities of LAC process in the manufacturing process are checked and found no interference from impurities. Stability studies, chemical development studies, routine batch analyses and quality control of the commercial product require a chemo- and enantioselective method capable of discriminating the enantiomeric API (Active Pharmaceutical Ingredient) from the related substances. Consequently, we turned our attention to examine the chemical selectivity of the Chiralpak IC using the n-Hexane- Ethanol (absolute 85:15, v/v) as a mobile phase. In these conditions, the LAC enantiomers were well separated and there was no overlapping with potential organic impurities. From Figure 3H, it can be seen that all the process and penultimate impurities were resolved with a k-value ranging from 1.1 to 1.3. The graphical approach for mobile phase composition verses USP resolutions (Figure 4).

Validation of the method

System suitability: The system suitability solution is prepared as mentioned in the preparation of the test solution and the control solution, to obtain a final concentration of LAC 1000 µg/mL spiked with 1.5 µg/mL of LAC enantiomer. The resolution is not less than 3.0 (Figure 3I).

LOD and LOQ: LOD and LOQ were established from S/N ratio methodology. LOD and LOQ were estimated to be 15 and 48 µg/mL for each enantiomer of (S)-LAC with good precision at LOQ. Precision at LOQ was established by calculating %RSD for replicate injections (n=6) of reference standard prepared at LOQ level. The determined LOD, LOQ limit of quantification and precision at LOQ values are reported in Table 1.
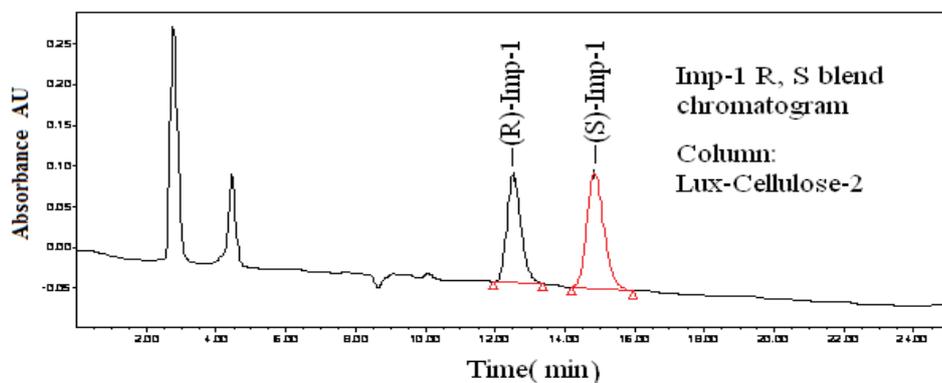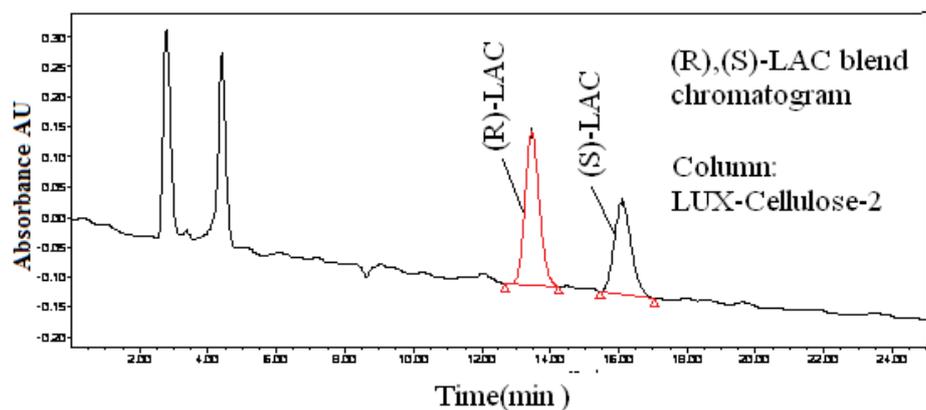
3A: Spiked chromatogram (Chiralcel-OD-H).
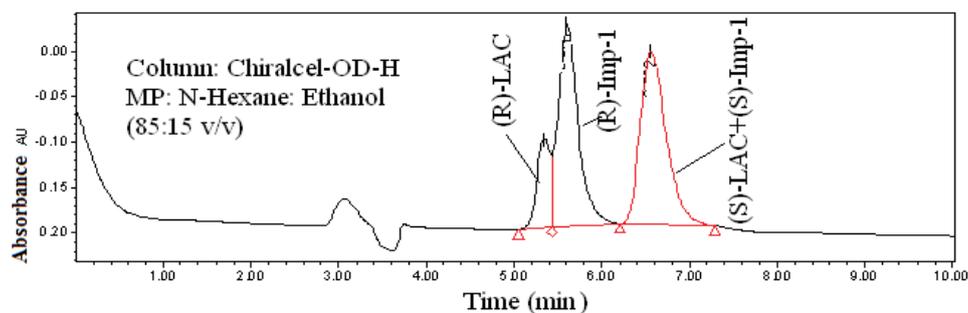
3B: Spiked chromatogram (Chiralpak-AS).
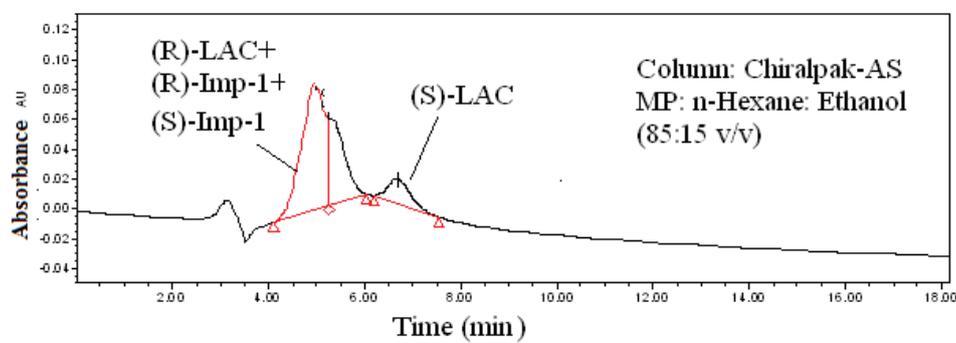
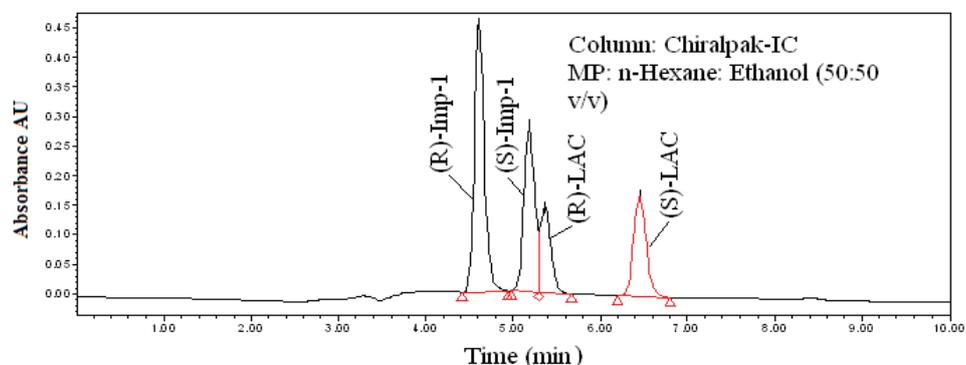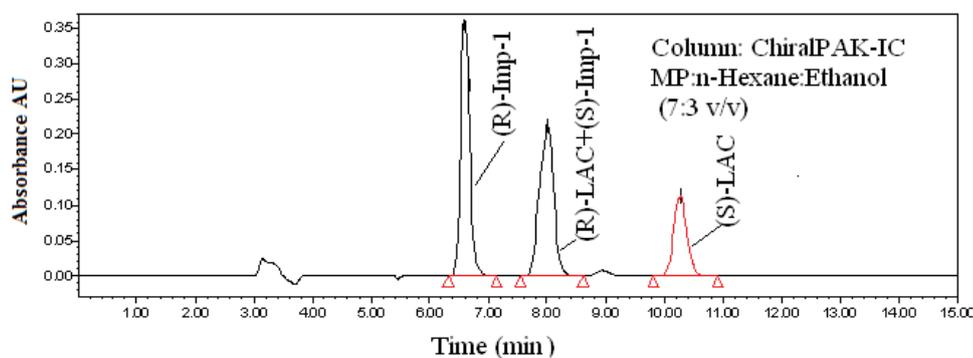3C: (R), (S)- Imp-1 spiked chromatogram (Lux cellulose-2).

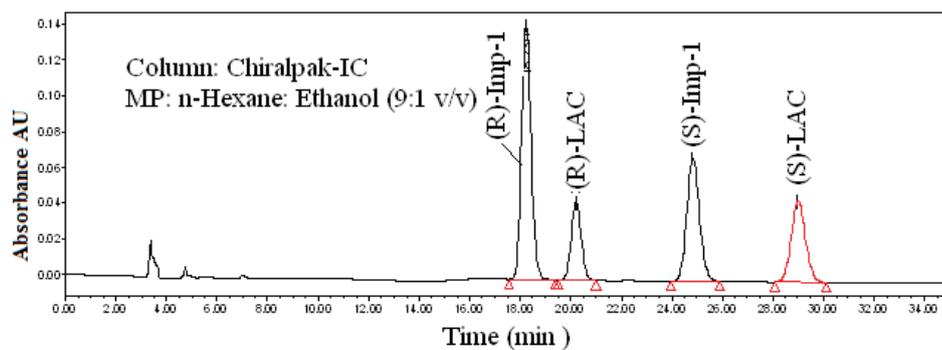3D: (R), (S)- LAC spiked chromatogram (Lux cellulose-2).

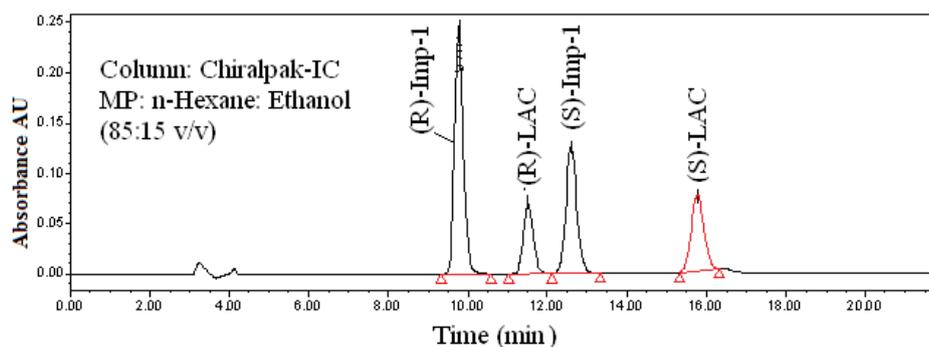3E: Spiked chromatogram (Chiralpak-IC MP: n-Hexane: Ethanol (50:50 v/v).

3F: Spiked chromatogram (Chiralpak-IC MP: n-Hexane: Ethanol (70:30 v/v).

3G: Spiked chromatogram (Chiralpak-IC MP: n-Hexane: Ethanol (90:10 v/v).

3H: Spiked chromatogram (Chiralpak-IC MP: n-Hexane: Ethanol (85:15 v/v).
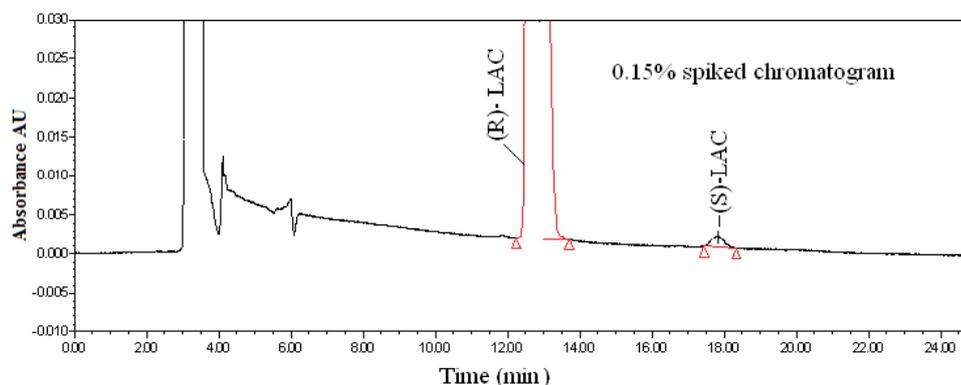
Figure 3: Blend Chromatogram of LAC and its impurities.

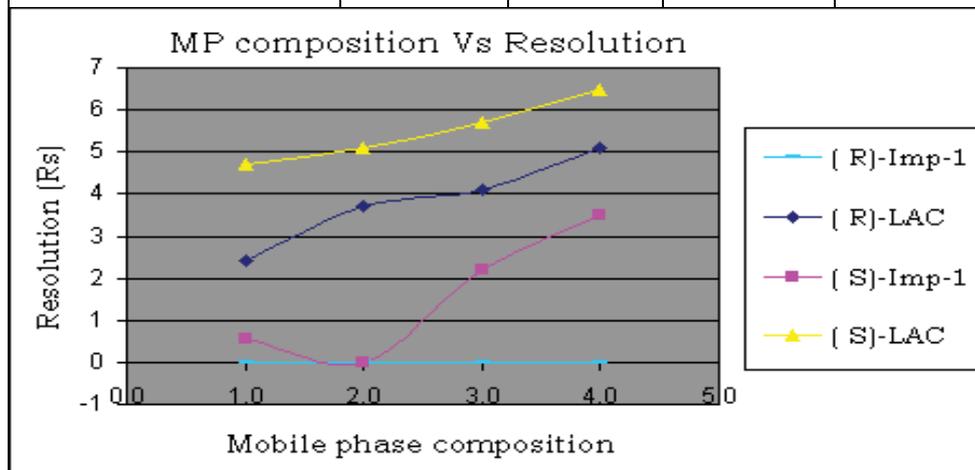| Mobile phase composition	(R)-Imp-1	(R)-LAC	(S)-Imp-1	(S)-LAC
n-Hexane: EtOH (1:1)	NA	2.4	0.6	4.7
n-Hexane: EtOH (7:3)	NA	3.7	0.0	5.1
n-Hexane: EtOH (85:15)	NA	4.1	2.2	5.7
n-Hexane: EtOH (9:1)	NA	5.1	3.5	6.5

Figure 4: Graphical representation for mobile phase composition verses USP resolution.

Precision/Repeatability/Method: Method reproducibility was determined by measuring repeatability, precision, and intermediate precision (between-day precision). Repeatability of the method was determined by calculating %RSD for the enantiomer area from replicate injections (n=6) of the system suitability solution. The %w/w values of the enantiomer for six different preparations of the system suitability solution were calculated. Method precision was determined by calculating %RSD for these %w/w values Table 1.

Intermediate precision was determined by performing method precision by a different analyst on a different day. The results in Table 2 show that method reproducibility was good.

Linearity: The linearity of the HPLC method was evaluated by injecting standard concentrations of racemic samples with a concentration ranging from LOQ to 150%, i.e, 0.48 µg/mL and 2.25 µg/mL for single enantiomer. The peak area response of the both enantiomers was plotted versus the nominal concentration of the enantiomer. The linearity was evaluated by linear regression analysis, which was calculated by least squares regression method. The obtained calibration curve showed correlation coefficient greater than 0.9994 for (S)-LAC. The following regression equation was obtained $y=251717x - 73.289$ ($R^2=0.9988$) where y is the peak area of (S)-LAC and x is the concentration. For (R)-LAC the following regression equation was obtained $y=244532x + 398592$ ($R^2=0.9999$).

Accuracy: Accuracy for the determination of enantiomeric composition was determined by preparing three drug substance samples at 50%, 100% and 150% of the target concentration (0.075%,

0.15% and 0.225%). Apparent recovery was ranged from 105% to 107%. Overall percent recovery was 106 (RSD%-0.8) for the enantiomer (S)-LAC Table 3.

Solution stability: Stability of the sample in the diluent was evaluated by injecting the freshly prepared spiked test solution every 6 h up to 48 h, at room temperature bench top solution. Physical appearance, for example, color of the solution did not change; no extra peaks appeared; and the cumulative relative standard deviation for the peak area of LAC enantiomer was less than 2.0%. Peak purity obtained from the photodiode array detector for the LAC enantiomer peak, showed that the peak was pure (purity angle is less than purity threshold). The results indicated that the solutions were stable up to 48 h at room temperature bench top solution.

Mobile phase stability: Mobile phase was also carried out for 48 h by injecting the freshly prepared spiked sample solutions for every 6 h interval. Physical appearance, no turbidity/haziness were observed mobile phase during analysis, Mobile phase prepared was kept constant during the study period with no extra peaks appeared, and the cumulative relative standard deviation for the peak area of LAC enantiomer was less than 2.0%. Peak purity obtained from the photodiode array detector for the LAC enantiomer peak, showed that the peak was pure (purity angle was less than purity threshold) Table 4.

Robustness: The robustness of a method is the ability of the method to remain unaffected by small but deliberate changes in parameters such as flow rate, mobile phase composition, and column oven temperature. The effect of resolution for the system suitability solution was monitored in this study. The flow rate of the mobile phase is 1.0 mL/min and was varied to 0.8 mL/min and 1.2 mL/min. The effect of change in percent organic, i.e., ethanol, (9:1; 8:2 v/v) ratio was studied by varying its concentration to -10 and +10% absolute, i.e., n-hexane: ethanol (90%:10%, v/v); n-hexane: ethanol (80%:20%, v/v). The column temperature is ambient (oven temperature maintained at 27°C) and was varied to 32°C and 22°C. The effects of each of these parameters were studied while the rest of the parameters were kept constant, as mentioned in an above section. The resolution remained unaffected by these small changes as shown in Table 5, thus proving the method to be rugged.

Discussion

A simple and new analytical chiral method has been developed for Lacosamide intermediate stages, Lacosamide drug product and its dosage forms. This method can be able to separate all process impurities. This method has been validated as per ICH and proved for specific. This method could be useful for reaction monitoring for synthesis of Lacosamide and its dosage forms.

Conclusion

In conclusion, a simple, sensitive, chemo- and enantio selective LC method for the quantitative determination of the enantiomers of LAC was developed and validated using the immobilised-type

Situation	Station	Resolution (Rs)	Tailing factor (T)	Spiked precision (n=6), %RSD
Different column	Column-1	8.58	1.13	0.6
	Column-2	7.92	1.12	7.4
Different analyst	Analyst-1	8.58	1.13	0.6
	Analyst-2	7.96	1.12	5.0
Different day	Day-1	8.58	1.13	0.6
	Day-2	8.10	1.12	1.0

Table 2: Ruggedness (Intermediate precision).

Concentration (%)	Sample ID	Amount added(%m/m)	Amount found(%m/m)	Recovery (%)	Statistical analysis
50	1	10.25	10.80	105.4	Mean:106.4
	2	10.28	10.98	106.8	SD:0.81
	3	10.15	10.84	106.8	%RSD:0.8
100	1	10.19	10.88	106.8	Mean:106.4
	2	10.04	10.72	106.8	SD:0.81
	3	10.25	10.80	105.4	%RSD:0.8
150	1	10.11	10.76	106.4	Mean:105.7
	2	10.28	10.84	105.4	SD:0.52
	3	10.19	10.74	105.4	%RSD:0.5

Table 3: Recovery data of Enantiomer.

Station	Impurity	Initial	Day-1	%Variation (relative)	Day-2	%Variation (relative)
MS	S-Isomer	0.154	0.148	0.006(+3.9%)	0.160	-0.006(-3.9%)
SS		0.154	0.144	0.01(+6.5%)	0.155	-0.001(-0.6%)

Table 4: Mobile phase stability and Solution stability study data.

Condition	Station	USP Resolution (Rs)	USP Tailing factor (T)	Relative retention time (RRT)
Mobile phase composition change (%)	90	9.11	1.16	1.41
	100	8.58	1.13	1.39
	110	8.23	1.14	1.38
Column oven temperature(°C)	22	8.48	1.12	1.40
	27	8.58	1.13	1.39
	32	7.95	1.10	1.36
Column flow (mL/min)	0.8	9.27	1.14	1.39
	1.0	8.58	1.13	1.39
	1.2	7.92	1.11	1.38

Table 5: Robustness.

Chiralpak IC CSP in normal-phase conditions. The proposed method meets the requirements of the all guidelines and is a reliable way to determine the enantiomeric purity of LAC penultimate stages and LAC in bulk drugs and pharmaceutical dosage forms. This method can be used for the routine analysis as well as the stability studies to evaluate (R) →(S), (S) →(R) isomerisation in pharmaceutical quality control.

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Parameter	Drug	Enantiomer
Calibration range (mg/mL)	LOQ-150%	LOQ-150%
Calibration points	6	6
Slope	244532	251717
Intercept	398592	-73.3
Residual sum of squares	0.9999	0.9988
Correlation coefficient	0.9999	0.9994

Table 1: Linearity of the developed chiral LC method.

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