

Stability-Indicating Reverse Phase HPLC Method Development and Characterization of Degradation Products of Valsartan and Sacubitril by Lc-Qtof-Ms/MS and NMR Studies

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Received November 24, 2022; Revised December 03, 2022; Accepted December 16, 2022

ABSTRACT

Sacubitril/Valsartan (SAC/VAL) is a combination drug used for the treatment of heart failure. VAL underwent significant degradation under acid hydrolytic, oxidative, photo and thermal stress conditions, while it was stable under base hydrolytic stress condition. SAC underwent significant degradation under hydrolytic (acid and base), oxidative stress conditions, while it was stable under photo and thermal stress condition. A total of six degradation products (DPs) were obtained. A simple, selective and reliable HPLC method has been developed for the separation of VAL, SAC and its DPs using Acquity Zorbax SB- C8 column (150 mm x 4.6 mm, 5 μ m) with mobile phase consisting of ammonium acetate (0.02 M, pH 3.0) buffer and acetonitrile (55:45, v/v). Chromatographic analysis was performed at flow rate of 1.0 mL/min using a PDA detector at a wavelength of 254 nm. The major DP of valsartan (VAL D-5) was characterized using LCMS based on mass fragmentation pattern and accurate m/z values. The major DPs of sacubitril (SAC D-2 and SAC D-3) were characterized by LCMS and extensive NMR (including 2D) spectroscopic methods. Study of NMR spectra (1D, 2D) and Mass spectrometry confirmed the suggested structures for sacubitril.

Keywords: Sacubitril, Valsartan, Degradation product, HPLC Method, Characterization, LC-MS/MS, NMR

INTRODUCTION

The parent ICH stability testing guideline requires the drug to be subjected to stress decomposition studies followed by identification and characterization of the degradation products. In parallel, the ICH guideline on impurities necessitates characterization of all degradation products formed in drug products at $\geq 0.1\%$. Therefore, the emphasis today is on techniques that allow characterization of very low quantities of degradation products, against the conventional process of isolation and spectral analysis, which is tedious and time consuming. The hyphenated techniques are in focus for the purpose, among which LC-MS tools have been explored more strongly due to their potential to directly characterize small quantities of degradation products.

A strategy was finalized for unequivocal elucidation of structures of degradation products present in minute amounts. An endeavor of the present study was to validate this strategy by its further application to forced decomposition samples of combination of sacubitril, a novel neprilysin inhibitor, with valsartan, an angiotensin receptor blocker [1-3].

Valsartan is chemically designated as N-(1-oxopentyl)-N-({2'-(2H-tetrazol-5-yl) [1,1'-biphenyl]-4-yl}methyl)-l-valine (VAL, **Figure 1a**) while Sacubitril calcium is chemically designated as 4 ((2S,4R)-1-(biphenyl-4-yl)-5-ethoxy-4-methyl-5-oxopentan-2-ylamino)-4-oxobutanoic acid calcium salt (SAC, **Figure 1b**) [4-9]. SAC is a prodrug that is hydrolyzed by esterases to sacubitrilat (**Figure 1c**). Sacubitrilat suppresses neprilysin enzyme which is responsible for the disintegration of two blood pressure-lowering natriuretic peptides. These peptides raise the level of cyclic guanosine-3', 5'-monophosphate, cause diuresis, natriuresis and vasodilation and also possess further anti

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Citation: Yadav P & Panchal H. (2023) Stability-Indicating Reverse Phase HPLC Method Development and Characterization of Degradation Products of Valsartan and Sacubitril by Lc-Qtof-Ms/MS and NMR Studies. J Pharm Drug Res, 6(2): 684-696.

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sympathetic and ant fibrotic effects. In addition, neprilysin enzyme assists in angiotensin breakdown. Concurrent inhibition of the renin-angiotensin-aldosterone system gives the entire advantages and benefits of neprilysin inhibition. Valsartan acts by selectively blocking an angiotensin II receptor subtype 1, present in the adrenal gland and vascular smooth muscle. In addition, valsartan hinders angiotensin II effect in the renin angiotensin system and also retards the advancement of chronic heart failure [1-3].

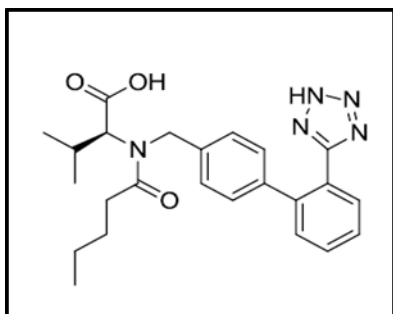


Figure1a. Structure of Valsartan.

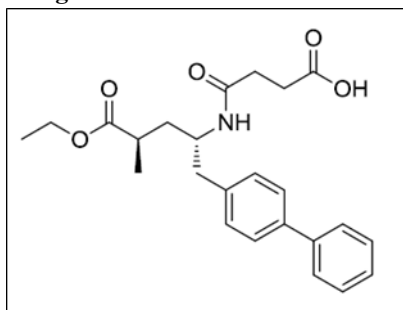


Figure1b. Structure of Sacubitril.

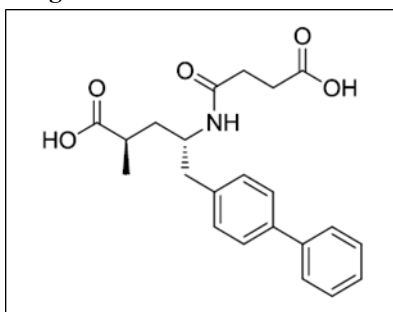


Figure1c. Structure of Sacubitrilat.

The degradation behavior of valsartan along with amlodipine was reported [10-24] but none of the degradation products were characterized. Hence it was of interest to study the same. The investigation involved the following steps: (1) subjecting of drugs to ICH prescribed hydrolysis, oxidative, photolytic and thermal stress; (2) separation of degradation products on an HPLC column; (3) establishment of fragmentation pattern of the drug using MS/TOF, MSⁿ and H/D exchange studies; (4) characterization of degradation products from LC-MS/TOF and online H/D exchange data

and NMR studies; and (5) justification of elucidated structures.

EXPERIMENTAL

Drugs and reagents

Pure standard of VAL was obtained as a gift sample from Lincoln Pharmaceutical Ltd., Gujarat, India and SAC from Cipla Pharmaceutical Ltd., Mumbai, India. Analytical reagent (AR) grade sodium hydroxide (NaOH) was purchased from Ranbaxy Laboratories, hydrochloric acid (HCl) from LOBA Chemie Pvt. Ltd. (Mumbai, India), and hydrogen peroxide (H₂O₂) from s.d.Fine-Chem Ltd. (Boisar, India). Buffer salts of AR grade and all other chemicals were bought from local suppliers. HPLC grade acetonitrile (ACN) was procured from J.T. Baker (Phillipsburg, NJ, USA). Ultra-pure water was obtained from a bench-top purification system (ELGA, Wycombe, Bucks, and UK). Deuterated water (D₂O, 99.9%) was obtained from Aldrich (St Louis, MO, USA).

Apparatus and equipment

Precision water baths equipped with MV controller (Julabo, Seelbach, Germany) were used for solution degradation studies. A Dri-Bath (Thermolyne, IA, USA) was used for solid state thermal stress study. Accelerated stability studies were carried out in humidity (KBF720, WTC Binder, Tuttlingen, Germany) and photostability (KBWF 240, WTC Binder, Tuttlingen, Germany) chambers, both set at 40 ± 1°C/75 ± 3% RH. The photostability chamber was equipped with an illumination bank on inside top, consisting of a combination of two UV (OSRAM L18 W/73) and four white fluorescent (PHILIPS TRULITE 18W/86) lamps, in accordance with Option 2 of the ICH guideline Q1B.[11] Both fluorescent and UV lamps were put on simultaneously. The samples were placed at a distance of 9 inches from the light bank. A calibrated lux meter (model ELM 201, Escorp, New Delhi, India) and a calibrated UV radiometer (model 206, PRC Krochmann GmbH, Berlin, Germany) were used to measure visible illumination and UV energy, respectively. pH/Ion analyzer (MA 235, Mettler Toledo, Schwerzenbach, Switzerland) was used to check and adjust the pH of buffer solutions. Other smaller equipment used were sonicator (3210, Branson Ultrasonics Corporation, Danbury, CT, USA), precision analytical balance (AG 135, Mettler Toledo, Schwerzenbach, Switzerland) and auto pipettes (Eppendorf, Hamburg, Germany). The degradation behavior of the drug was studied on a liquid chromatography (LC) system equipped with a photodiode array detector and controlled by SP1 software ver. 6.14 (VP series, Shimadzu, Kyoto, Japan). MSⁿ studies were carried out on an LTQ XL MS 2.5.0 system (Thermo, San Jose, CA, USA). The same was controlled by Xcalibur (version 2.0.7 SP1) software. LC-MS/TOF results were obtained on a system in which HPLC (1100, Agilent Technologies, Waldbronn, Germany) was hyphenated to MicrOTOF-Q spectrometer (Bruker

Daltonik, Bremen, Germany), using Hyphenation Star (version 3.1) and MicroTOF Control (version 2.0) software. The calibration solution used was ES Tuning Mix solution (Agilent Technologies, Palo

Alto, CA, USA), diluted to a suitable concentration with a mixture of ACN-water (95: 5%v/v). All masses were corrected by use of internal reference ions of m/z 322.0481 ($C_6H_{19}O_6N_3P_3$), 622.0290 ($C_{12}H_{19}O_6N_3P_3F_{12}$), and 922.0098 ($C_{18}H_{19}O_6N_3P_3F_{24}$). The TOF instrument was also used for H/D exchange study on the drug, while MSn system was employed for online H/D exchange investigations on the degradation products. In all the studies, the separations were achieved on a Luna C-18 (150 mm $\times$ 4.6 mm i.d., particle size 5 μ m) column (Phenomenex, Torrance, CA, USA).

Stress studies [25,26]

For Valsartan and Sacubitril, Acidic and alkaline hydrolysis were carried out in 2N HCl and 2N NaOH, respectively. All the hydrolytic studies were conducted at 75°C for 1 h. The oxidative study was carried out in 15% H_2O_2 at room

temperature for 5 h. Photolytic studies on the drug in the solid and solution state were carried out by exposure to a combination of UV lamps in a photostability chamber for 24 h. A parallel blank set was kept in the dark for comparison. For thermal stress testing, the drugs were sealed in glass vials and placed in the thermostatic block at 121°C for 3 days. After subjecting the samples to stress studies, they were withdrawn at suitable time intervals and diluted with mobile phase to make final concentration for VAL 20 μ g/ml and SAC 20 μ g/ml before LC injection. All the prepared sample solutions were filtered through 0.22 μ m nylon syringe filters prior to the injection in HPLC. From the individual stress studies of Valsartan and Sacubitril, identify the degradants of valsartan are found to be DP-1, DP-4, DP-5 and DP-6 named VAL D-1, VAL D-4, VAL D-5 and VAL D-6 respectively while degradants of Sacubitril are found to be DP-2 and DP-3 named SAC D-2 and SAC D-3 respectively shown in **Figure 2**.

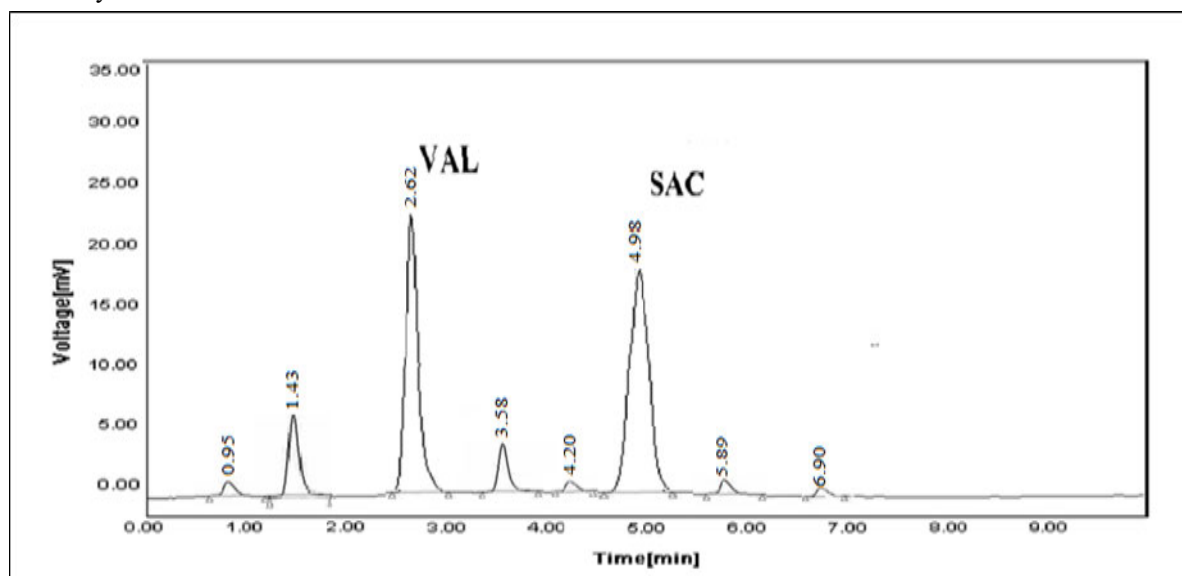


Figure 2. Chromatogram showing separation of DPs (1-6), Valsartan and Sacubitril in the mixture of stressed samples.

Analytes	Valsartan	Valsartan	Valsartan	Valsartan	Sacubitril	Sacubitril
DP Peaks	VAL D-1	VAL D-4	VAL D-5	VAL D-6	SAC D-2	SAC D-3
Stress Conditions	Alkaline	Oxidative	Oxidative and Photo	Oxidative and Photo	Acid and Alkaline	Acid

HPLC method development and optimization

Various trials were conducted for the method development. Final chromatographic separation was achieved on Zorbax SB C8, (150 $\times$ 4.6) mm; 5 μ m column. In the optimized method, the mobile phase consisted of a mixture of 0.02 M

ammonium acetate buffer and acetonitrile (55:45, %v/v) and pH of the mobile phase was set at 3.0 using glacial acetic acid. The flow rate was set at 1.0 ml/min; the injection volume was kept 20 μ l. The samples were scanned in the range of 200-400 nm using a PDA detector and the monitoring wavelength was set at 254 nm.

MS/TOF, MSⁿ and H/D exchange studies on the drug

In order to establish a comprehensive fragmentation pathway of the drugs, MS/TOF studies were performed in ESI positive mode in the mass range of 50 to 1500 Da. High purity nitrogen was used as a nebulizer as well as an auxiliary gas. Mass parameters were optimized, as listed in

Table 1. The drugs were further subjected to multistage mass studies (MSⁿ) in ESI positive mode. Fragmentation of various precursor ions formed in MSⁿ studies was achieved at different collision energies. This was followed by conduct of H/D exchange studies on the drug, wherein the drugs solutions were prepared in a mixture of CH₃CN and D₂O.

Table 1. Parameters of the developed MS/TOF methods in ESI +ve mode.

Purpose	Parameters	Molecular ions of drug/degradation product	Optimum fragmentation
Source	End plate offset (V)	-500	-500
	Capillary (V)	-4500	-4500
	Nebuliser (Bar)	1.2	1.2
	Dry gas (L/min)	6.0	6.0
	Dry temperature (°C)	200	200
Transfer	Funnel 1 RF (Vpp)	150	200
	Funnel 2 RF (Vpp)	200	250
	ISCID energy (eV)	0.0	7.0
	Hexapole RF (Vpp)	280	280
Quadrupole	Ion energy	4.0	10.0
	Low Mass (m/z)	200	300
Collision Cell	Collision energy (eV/z)	7.0	20.0
	Transfer time (μs)	36.0	48.0
	Collision RF (Vpp)	300	300
	Pre pulse storage (μs)	16.0	10.0
Detector	Source(V)	-1200	-1200

LC-MS/TOF studies on degradation products

The stressed samples were subjected to LC-MS/TOF studies using the developed LC method having ammonium acetate at same buffer concentration and pH. The identity of each degradation product was established with the help of LC-MS/TOF accurate mass values, and comparison of fragmentation profiles with the drugs.

Nuclear Magnetic Resonance Studies

For Sacubitril, Both degradation impurities were dissolved individually in DMSO-d₆ solvent and recorded the spectra of ¹H, ¹³C, ¹H-¹H COSY, ¹H-¹³C HSQC, and ¹H-¹³C HMBC of these degradant products from 400 MHz w.r.t. ¹H NMR spectrometer equipped with the multinuclear probe. Methylated silanes like SiMe₄ (TMS) [(Me = CH₃)] were taken as an internal reference compound and relatively this,

¹H and ¹³C nuclear chemical shifts are reported using ppm units with a reference SiMe₄ (TMS). The spectra were recorded by referencing Tetra Methyl Silane to δ 0.0 ppm in both ¹H and ¹³C NMR, and δ 2.5 ppm, δ 39.50 ppm in ¹H, ¹³C NMR respectively.

RESULTS AND DISCUSSION

Degradation behavior of valsartan and sacubitril

The Valsartan degraded an extent of 15.95%, 20.08%, 10.04% and 12.21% under acid, oxidative, photo and thermal conditions, respectively to form one degradation product (VAL D-5). The Sacubitril degraded an extent of 32.33%, 36.71% and 2.98% under acid, alkali and oxidative conditions, respectively to form two degradation products (SAC D-2 and SAC D-3). The Valsartan was stable under stress condition, including hydrolysis in alkali; exposure to UV light while the Sacubitril was stable under photo and thermal stress conditions (**Figures 3 & 4**).

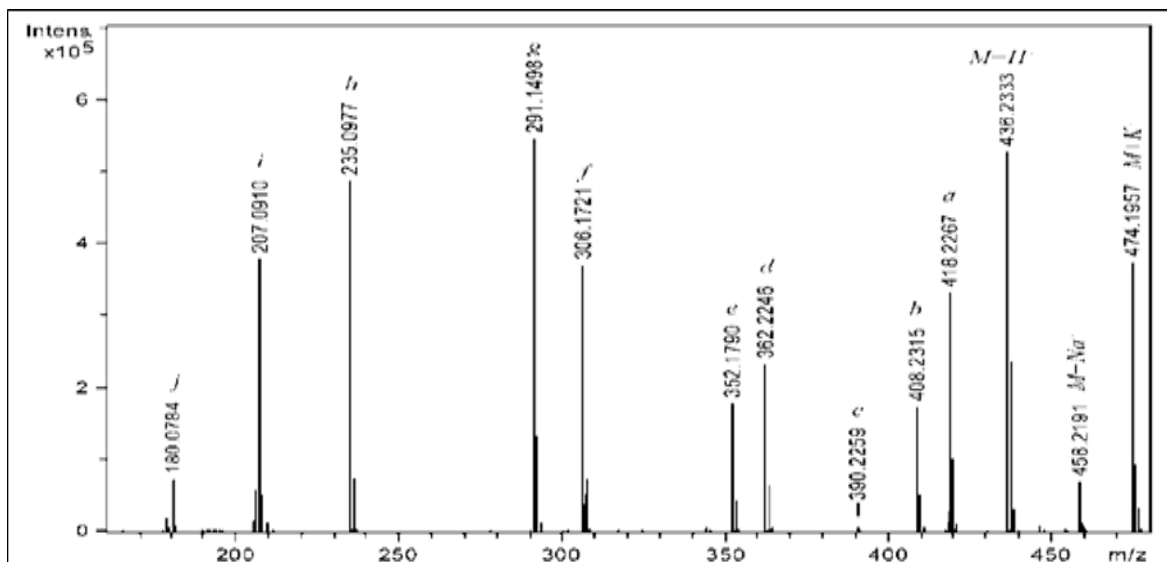


Figure 3. Line spectrum of valsartan obtained in MS/TOF study.

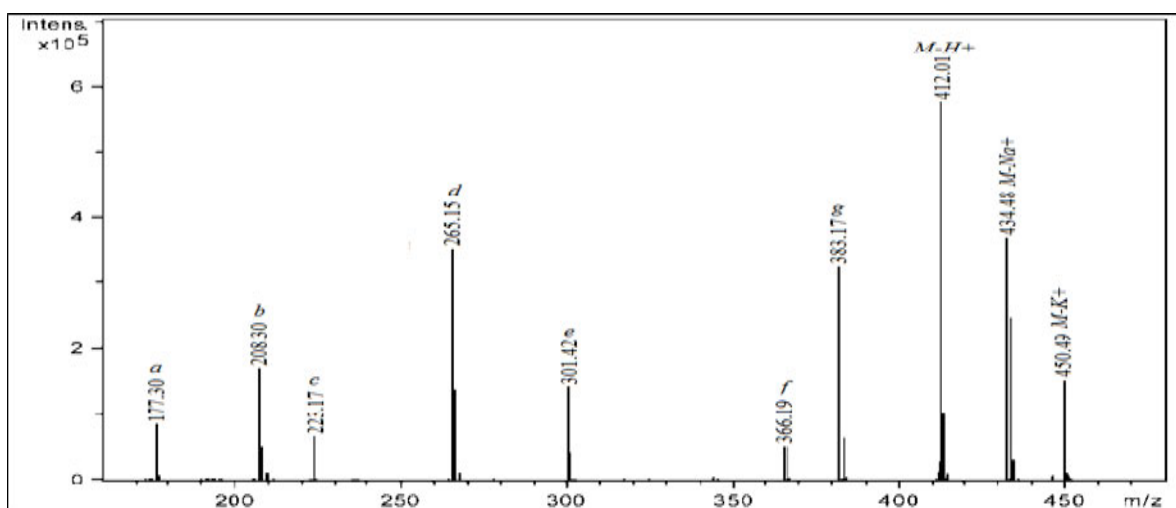


Figure 4. Line spectrum of sacubitril obtained in MS/TOF study.

Mass fragmentation behavior of the valsartan and sacubitril

Figures 1 & 2 shows line spectrum of the valsartan and sacubitril obtained from MS/TOF studies, respectively. In total, ten fragments (labeled 'a-j') were formed from valsartan ($M+H^+$), apart from Na and K adducts and seven fragments (labeled 'a-g') were formed from sacubitril ($M+H^+$), apart from Na and K adducts. The accurate mass of each fragment was used to determine the most probable molecular formula (Table 2), taking the help of elemental composition calculator. Subsequently, MS^n studies were performed on the valsartan to determine the origin of each fragment. This was followed by proposition of tentative structures to each, also taking into account data from H/D

exchange studies, and calculated values of ring plus double bonds (RDBs). The fragmentation behavior of valsartan correlated to data in Table 2 is outlined in Figure 4. The figure shows existence and involvement of three possible protonated forms of the precursor [m/z 436] in the valsartan fragmentation pathway. The precursor with protonation at the carboxylic group produced a daughter ion of m/z 418, whereas those charged at amide nitrogen and tetrazole nitrogen reduced to ions of m/z 408 and 352, respectively. The ion of m/z 418 further fragmented in MS^3 step into an ion of m/z 390, which on MS^4 resulted in two parallel daughter fragments of m/z 362 and 306. The ion of m/z 362, on further MS^4 and MS^5 analyses fragmented to m/z 347 $\rightarrow$ 291, while the one of m/z 306 followed the pathway m/z 235 $\rightarrow$ 207 $\rightarrow$ 180.

Table 2. Interpretation of MS/TOF, H/D exchange and MSⁿ data of fragments of Valsartan.

Peak no.	MS/TOF data	Best possible molecular formula	Exact mass of most probable structure	Error in ppm	RDB	Possible parent fragment	Difference from parent ion	Possible molecular formula for loss		H/D Exchange data	No. of labile hydrogens	
								L1	L2		M+H+	M+
M+H⁺	436.2333	C ₂₄ H ₃₀ N ₅ O ₃	436.2343	-2.2	12.5	-	-	-	-	439	3	2
a	418.2267	C ₂₄ H ₂₈ N ₅ O ₂	418.2238	6.9	13.5	M+H+	18.0066	H ₂ O	-	419	1	0
b	408.2315	C ₂₄ H ₃₀ N ₅ O ₃	408.2282	8.0	11.5	M+H+	28.0018	N ₂	-	411	3	2
c	390.2259	C ₂₃ H ₂₈ N ₅ O	390.2288	-7.4	12.5	a	28.0008	N ₂	CO	391	1	0
d	362.2246	C ₂₃ H ₂₈ N ₅ O	362.2227	5.2	11.5	b,c	-	CH ₂ O ₂ , N ₂	-	363	1	0
e	352.1790	C ₁₉ H ₂₂ N ₅ O ₂	352.1768	6.2	11.5	M+H+	84.0543	C ₃ H ₆ N ₃	C ₃ H ₈ O	356	4	3
f	306.1721	C ₁₈ H ₂₀ N ₅	306.1713	2.6	11.5	c,e	-	C ₅ H ₈ O, CH ₂ O ₂	C ₃ H ₆ N ₃	308	2	1
g	291.1498	C ₁₉ H ₁₉ N ₅ O	291.1492	2.0	11.5	*	-	-	-	292	1	0
h	235.0977	C ₁₄ H ₁₁ N ₄	235.0978	-0.4	11.5	f	71.0743	C ₄ H ₉ N	-	236	1	0
i	207.0910	C ₁₄ H ₁₁ N ₄	207.0917	-3.3	10.5	h	28.0067	N ₂	-	208	1	0
j	180.0784	C ₁₃ H ₁₀ N	180.0808	-13.3	9.5	*	-	-	-	181	1	0

*MSⁿ study could not be achieved

LC-MS/TOF and on-line H/D exchange studies on degradation product of valsartan (VAL D-5)

Subsequent to establishment of mass fragmentation pattern for the valsartan, the VAL D-5 was also subjected to LC-

MS/TOF analyses to elucidate their structures. The mass spectra obtained thereof are shown in Figure 6. The data of accurate masses, possible molecular formulae, major fragments and on-line H/D exchange for the VAL D-5 are enlisted in **Table 3**.

Table 3. MSⁿ fragmentation of Valsartan.

MS ⁿ	Precursor ion	Product ions
MS²	436	418,408,362,352,291,235,207
MS³	418	390,362,306,235,207
	408	362,291
	352	306,235,207
MS⁴	390	362,347,306,235,207
	362	347 ^a ,291 ^a
	306	235,207,180
MS⁵	235	207 ^a , 180

^aFragments had low intensity, so could not be captured for further MSⁿ

Characterization of VAL D-5

The VAL D-5 was characterized through systematic amalgamation of HRMS, mass fragmentation and on-line H/D exchange data.

VAL D-5

The HRMS value of VAL D-5 was 352.1762 (**Figure 6 & Table 4**). Its major fragments had m/z of 306, 235, 207 and 180. All these fragments were also formed from the product ion of m/z 352.1768 in case of the Valsartan drug

(**Figure 6**). This clearly meant that VAL D-5 had the same structure as the drug fragment of equal mass. The same was supported by the presence of three labile hydrogens (as determined by H/D exchange study) and very small error of - 1.7 ppm between exact and observed masses. The proposed structure of VAL D-5 is shown in **Figure 7**. The interpretation using Mass data and fragmentation data confirms that the degradation product VAL D-5 is named to be as 3-methyl-2-({[2'-(1H-1,2,3,4-tetrazol-5-yl)-[1,1'-biphenyl]-4-yl]methyl}amino)butanoic acid.

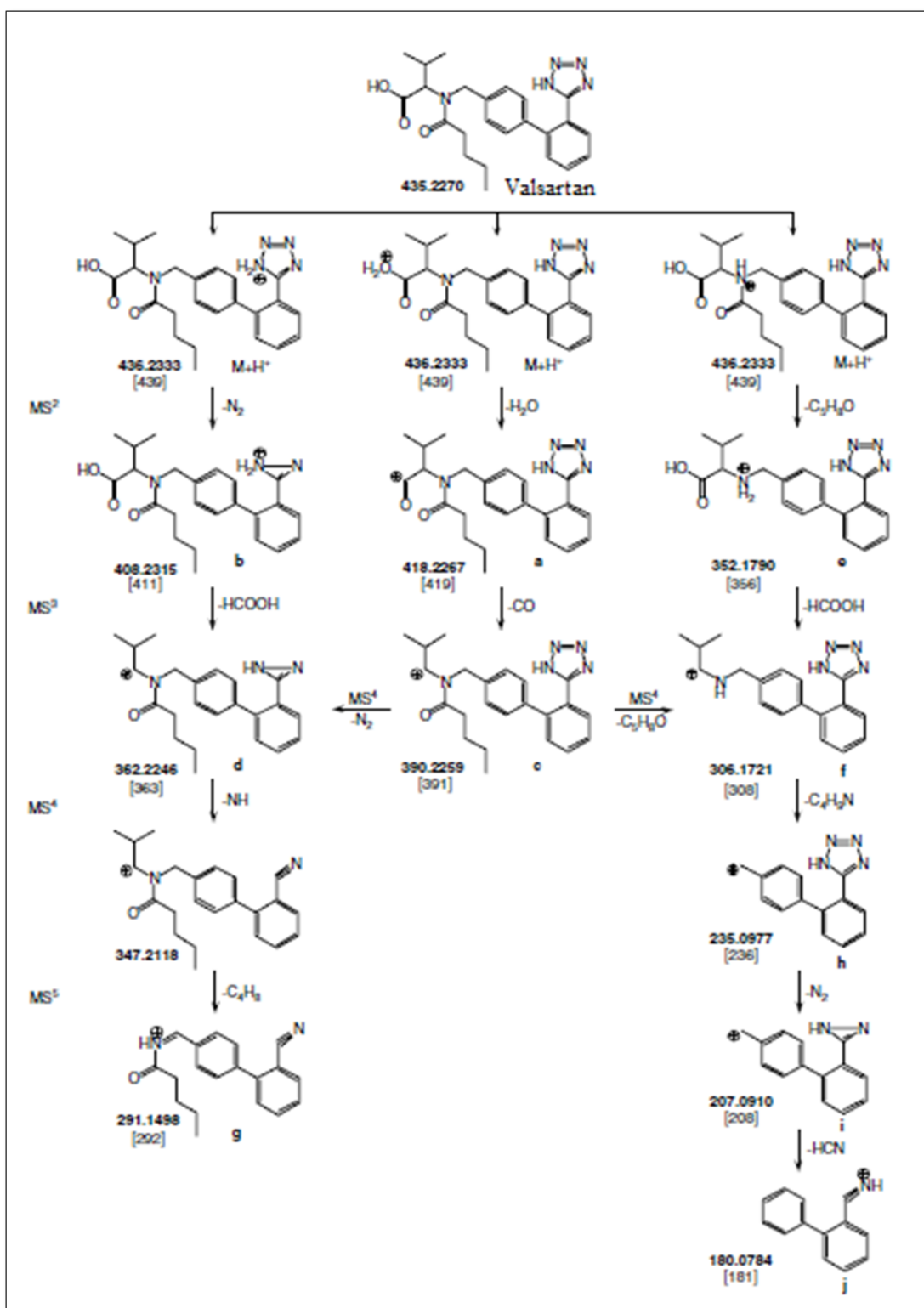


Figure 5. Fragmentation pathway of Valsartan. The value of obtained accurate mass is shown below each structure, along with the mass obtained in H/D exchange study (in square brackets). M+H⁺ denotes the protonated form of precursor; while a-j represent fragments in the line spectrum shown in Figure 2.

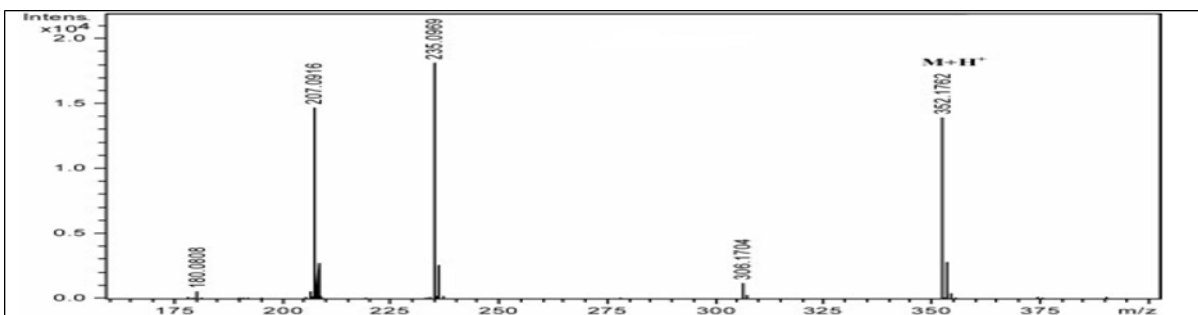


Figure 6. Line Spectra of Valsartan degradation product (VAL D-5).

Table 4. MS/TOF and online H/D exchange data of VAL D-5 along with their molecular formulae and major fragments.

DPs	Accurate mass	Molecular formulae (Exact mass; RDB; error in ppm)	Major fragments (Chemical formulae; error in ppm)	Mass after H/D exchange in ESI +ve mode	Number of labile hydrogens
VAL D-5	352.1762	$C_{19}H_{22}N_5O_2^+$ (352.1768; 11.5; -1.7)	306.1704 ($C_{18}H_{20}N_5^+$; - 2.9), 235.0969 ($C_{14}H_{11}N_4^+$; - 3.8), 207.0916 ($C_{14}H_{11}N_2^+$; - 0.4), 180.0808 ($C_{13}H_{10}N^+$; 0.0),	356	3

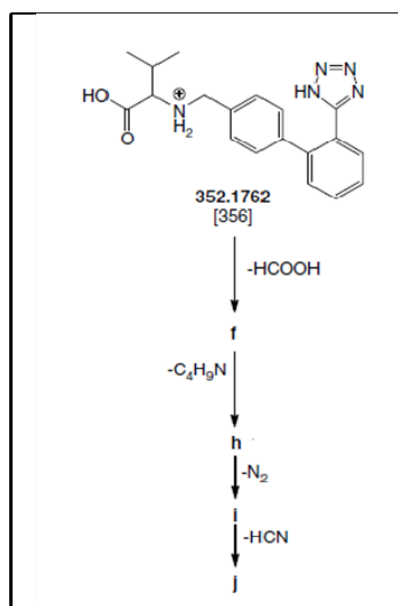


Figure 7. Fragmentation pattern of DP of Valsartan (VAL D-5). The value of obtained accurate mass is shown below each structure along with the mass obtained in online H/D exchange study.

Isolation of Degradation Products of Sacubitril (SAC D-2 and SAC D-3)

For Sacubitril, Two base degradation products (SAC D-2 and SAC D-3) have been found in the acid and base degradation study and the same were identified with the LC-MS technique (as mentioned above section) and found the molecular ion peak at 383.17 and 265.15 corresponding to SAC D-2 & SAC D-3 respectively. After many injections, a

few liters of organic solvents were collected by using an optimized condition in preparative HPLC (as mentioned above section). The peaks are almost baseline-separated, which leads to high purity and yield. At the end of a sequence of purification runs, the collected fractions evaporated from the fraction container into the laboratory air. Refer to the chromatograms of acid and base degradants product in **Figures 8 & 9**.

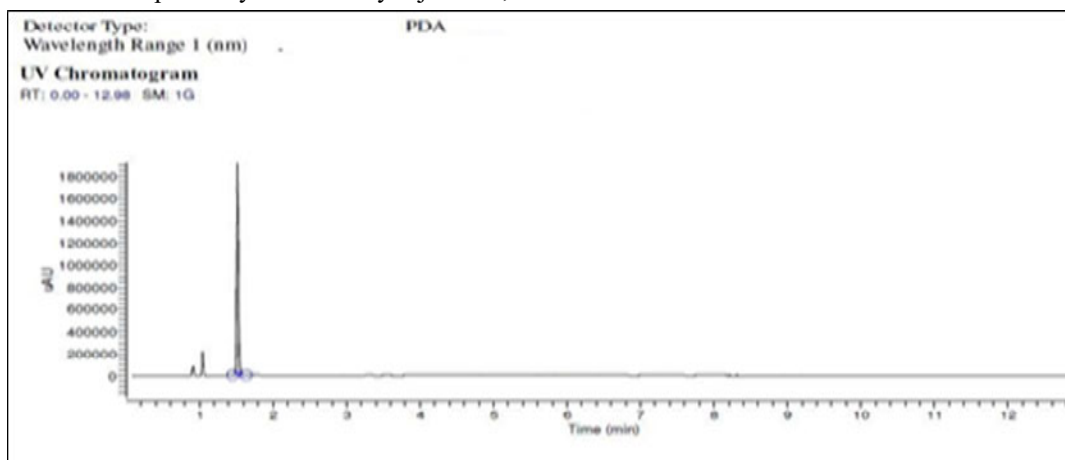


Figure 8. Chromatogram of acid and base Degradants Product (SAC D-2).

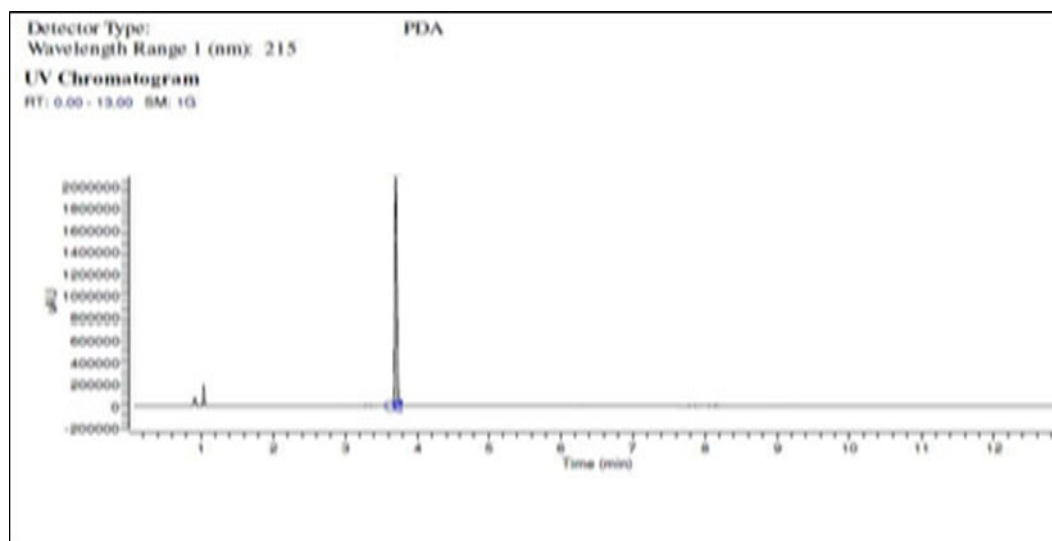


Figure 9. Chromatogram of acid Degradants Product (SAC D-3).

The Sacubitril was subjected to stress degradation as mentioned in stress studies, viz., acid hydrolysis, base hydrolysis, thermal, oxidative, and photolytic degradation. Based on the chromatographic data, it was observed that the Sacubitril calcium was degraded more extensively in acid and base hydrolysis. The degraded Sacubitril calcium impurities were isolated using preparative chromatography, and the isolated impurities were again injected to confirm the retention time. These two degradation products are

tagged as SAC D-2 and SAC D-3. The Sacubitril calcium eluting at a retention time of 3.98 min and the degradants SAC D-2 and SAC D-3 elute at retention times of 1.51 min and 3.73 min, respectively. These impurities were isolated using preparative chromatography and then subjected to structural elucidation using mass spectrometry and NMR spectroscopy to assign the structures. Refer to below **Table 5** for the δ values in ppm of NMR of Sacubitril calcium, SAC D-2 & SAC D-3.

Table 5. Molecular Masses, ^1H -NMR, and ^{13}C NMR, and Heteronuclear NMR Correlation Data of Sacubitril calcium and Degradation Products (SAC D-2 and SAC D-3).

Assignment	SAC API		EM-383.99		EM-265.09	
			SAC D-2		SAC D-3	
	^1H	^{13}C	^1H	^{13}C	^1H	^{13}C
1	7.44	128.9	7.45	128.9	7.46	128.9
2	7.33	127.2	7.34	127.2	7.35	127.2
3	7.44	128.9	7.45	128.9	7.46	128.9
4	7.65	126.5	7.65	126.5	7.66	126.5
5		140		140.1		139.9
6	7.65	126.5	7.65	126.5	7.66	126.5
7		137.8		137.8		138
8	7.57	126.3	7.58	126.3	7.6	126.47
9	7.26	129.8	7.27	129.9	7.32	130
10		138.2		138.1		137.3
11	7.26	129.8	7.27	129.9	7.32	130
12	7.57	126.3	7.58	126.3	7.6	126.47
13	2.64,2.73	40.7	2.73	40.3	2.68,2.82	41
14	3.92	48	3.99	48.5	3.74	52.1
15	1.40,1.75	37.7	1.37,1.80	37.8	1.63,1.99	33.7
16	8.28		7.79		7.76	
17		172.8		170.7	2.17	34
18	2.22	33.6	2.42	29.5		178.7
19	2.11	34.3	2.32	30.4	0.98	16
20						
21		176.6		174		
22						
23						
24	2.5	36	2.46	35.9		
25		175.5	1.07	18.1		
26	1.05	18		177.2		
27						
28						
29	4	59.7				
30	1.11	14				

Structure Elucidation of Sacubitril

The Mass spectroscopic analysis using positive polarity with Electro Spray Ionization technique showed the molecular mass as 412.01 Daltons (as M+H). Based on this mass data, the molecular mass of Sacubitril sodium was confirmed as 411 Daltons. The ^1H NMR spectrum exhibited 27 protons, of which 18 protons were from aliphatic chains and 9 protons are from the aromatic regions. Similarly, the ^{13}C NMR showed 24 carbons of which 9 carbons were from the aliphatic region and 15 carbons from the aromatic region. The ^1H - ^{13}C correlation spectrum confirmed that there are 11 methyne, 5 methylene and 2 methyl groups present. Further confirmation of structure and assignments of ^1H and ^{13}C signals were established by NMR studies by correlating ^1H - ^1H and ^1H - ^{13}C data. Refer to table-5 below for details.

Structure Elucidation of SAC D-2

The Mass spectroscopic analysis using positive polarity with Electro Spray Ionization technique showed the molecular mass as 383.17 Daltons (as M+H). Based on this mass data the molecular mass of SAC D-2 was confirmed as 383 Daltons. The ^1H NMR spectrum of SAC D-2 exhibited 22 protons of which 13 protons are from the aliphatic region and 9 protons are from the aromatic region, one labile proton with broad signal arising from -NH group, and two labile protons with broad signal due to acidic protons are observed. Ethyl ester protons which were observed in Sacubitril proton NMR were absent in ^1H NMR of SAC D-1. ^{13}C NMR is complimenting the ^1H NMR in that 2 aliphatic carbons are absent in its spectrum when compared to Sacubitril drug ^{13}C

NMR spectrum. This confirms that Ethyl ester in Sacubitril was converted into acid during base degradation. The ^{13}C Spectra of SAC D-2 exhibited 7 aliphatic carbons and 15 aromatic carbons. The ^1H - ^{13}C correlation NMR data confirmed that SAC D-1 had 11 methyne, and 4 methylene, one methyl group present in the 2D-NMR spectrum. Further, the SAC D-2 subjected to Hetero nuclear Multi Bond correlation NMR spectroscopy (i.e. ^1H - ^{13}C multi bond correlation) and interpretation from this study confirmed the assigned structure as 5-([1,1'-biphenyl]-4-yl)-4-(3-carboxypropanamido)-2-methylpentanoic acid.

Structure Elucidation of SAC D-3

The Mass spectroscopic analysis using positive polarity with Electro Spray Ionization technique showed the molecular mass as 265.15 Daltons (as M+H). Based on this mass data, the molecular mass of SAC D-3 was confirmed as 265 Daltons. The ^1H NMR spectrum of SAC D-3 exhibited 18 protons of which 9 protons are from the aliphatic region and 9 protons are from the aromatic region, and one labile proton with a broad signal arising from the -NH group was observed. ^{13}C NMR is complimenting to the ^1H NMR that 5 carbons detected in the aliphatic region and 13 carbons detected in the aromatic region. The ^1H - ^{13}C single bond and multi bond correlation NMR study show that SAC D-2 had 11 methyne groups, 2 methylene groups, and one methyl group in the spectrum. The interpretation using Mass data and NMR data confirms that the isolated degradation product SAC D-3 is named to be as (3S)-5-([1, 1'-biphenyl]-4-ylmethyl)-3-methylpyrrolidin-2-one (**Figures 10-12**).

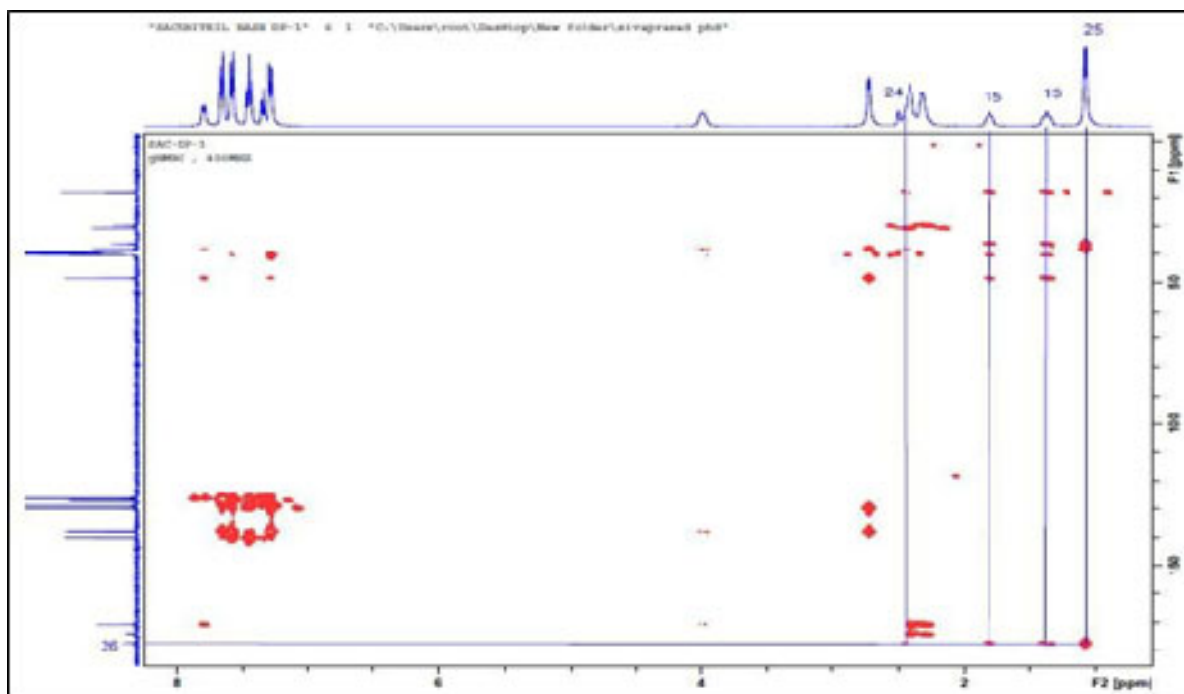


Figure 10. HMBC information of SAC D-2.

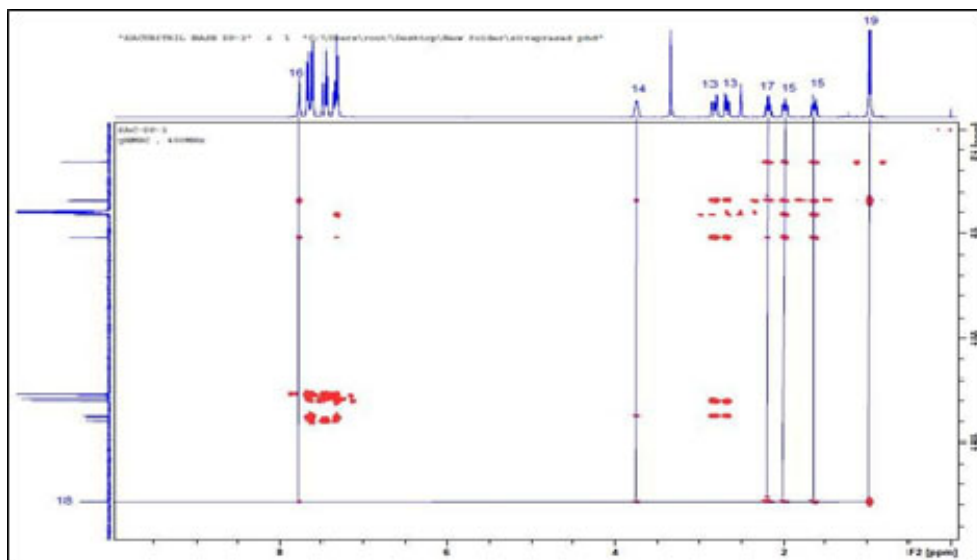


Figure 11. HMBC information of SAC D-3.

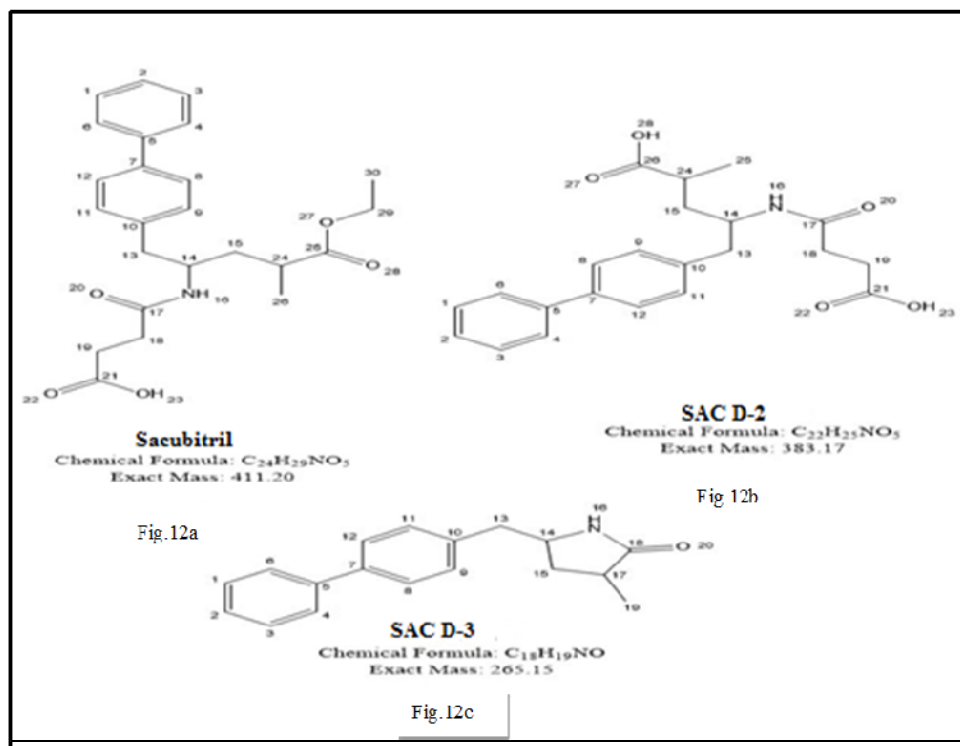


Figure 12. Structure of Sacubitril (12a) and Sacubitril degradation compounds (12b, 12c).

CONCLUSION

The degradation behavior of Valsartan and Sacubitril were explored under stress degradation conditions prescribed by ICH guidelines. The drugs underwent acid, base hydrolysis and oxidative, photo, thermal degradation conditions. To characterize the three degradation products, the strategy was employed. First a complete fragmentation pathway of the valsartan was established using MS^n and MS/TOF data. The

DPs were then subjected to LC-MS/TOF analysis and structures were proposed based on their accurate mass and H/D exchange data, and also through comparison of fragmentation pathway of VAL D-5 to that of the valsartan. The degradation product of valsartan VAL D-5 was characterized successfully by LC and LC-MS techniques. Two degradation products, SAC D-2, and SAC D-3 were formed during acid and base hydrolysis of the Sacubitril drug substance. All the degradants were isolated &

unambiguously characterized by LCMS and NMR techniques. Structure elucidation of the degradation product SAC D-2 and SAC D-3 were carried out by Mass spectrometry and ^1H , ^{13}C , and 2D-NMR techniques.

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