

Design, Synthesis and Preliminary Antimicrobial Evaluation of New Derivatives of Cephalixin

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Abstract

There is a continuous and massive need for newer cephalosporins that should have resistance against β -lactamases and can be used orally. An approach of using cephalixin, as a well-studied and potent antibacterial compound is considered to prepare new designed derivatives. These derivatives include the incorporation of amino acid moiety linked through an amide bond with the α -amino group of cephalixin. Certain aliphatic amino acids were used, such as glycine, alanine, valine and proline. The chemical structures of these derivatives were confirmed by IR spectroscopy and elemental analyses. All the synthesized compounds were subjected for preliminary evaluation of antimicrobial activity using well diffusion method, against certain microbes. Most of the synthesized compounds were found to possess significant antibacterial activities. Compound 1 (125 μ g and 250 μ g) showed significant activity against *P. aeruginosa*. Compound 2 (125 and 250 μ g) exhibited significant activity against *P. aeruginosa* and *Bacillus cereus*. Compound 3 (125 and 250 μ g) demonstrated very significant activity against *E. coli*, *P. aeruginosa* and *Bacillus cereus* and slight activity towards *S. aureus*. Compound 4 (250 μ g) showed significant activity against *P. aeruginosa* and no antibacterial activities against *E. coli*, *S. aureus* and *Bacillus cereus*, as compared with cephalixin as the standard compound.

Keywords: Cephalosporins, Cephalixin, Glycine, Alanine, Valine, Proline.

تصميم وتحضير والتقييم الاولي للفعالية المضادة للبكتيريا لمشتقات جديدة لعقار السيفالوكسين

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الخلاصة

اتضح من الدراسات والبحوث العلمية بان هناك حاجة كبيرة لمضادات حيوية من نوع السيفالوسبورينات المقاومة للبكتيريا المنتجة لانزيمات البيتا لاكتاميز والتي قد تستعمل عن طريق الفم. استخدم السيفالوكسين لتحضير مشتقات جديدة بواسطة ربط الاحماض الامينية عن طريق مجموعة الكاربوكسيل بمجموعة الامين الاولية (حره) الموجوده في جزيئة السيفالوكسين وتكوين اصرة اميد باستعمال الاحماض الامينية الالفاتية مثل الكلايسين، الالنين، فالين، والبرولين. تم تشخيص التراكم الكيمياوية لهذه المشتقات بواسطة التحليل الطيفي (الاشعة تحت الحمراء) والتحليل الدقيق للعناصر (الكاربون والهيدروجين والنترجين) وكانت النتائج مطابقه للتركيبات الكيمياوية المقترضة. تمت دراسة الفعالية المضادة للبكتيريا باستعمال بعض الميكروبات المرضية واطهرت النتائج بان المركب ١ (١٢٥-٢٥٠ مايكروغرام) لديه فعالية متميزة ضد الزائفة الزنجارية، بينما المركب ٢ (١٢٥-٢٥٠ مايكروغرام) فقد اظهر فعالية ضد الزائفة الزنجارية والبكتريا العصوية الشمعية. في حين ان المركب ٣ (١٢٥-٢٥٠ مايكروغرام) اظهر فعالية جدا متميزة ضد الزائفة الزنجارية والبكتريا العصوية الشمعية و الاشريكية القولونية. اما المركب ٤ (٢٥٠ مايكروغرام) فقد اظهر فعالية متميزة ضد الزائفة الزنجارية ولم يظهر أي فعالية لبقية المايكروبات وقد استعمل عقار السيفالوكسين كمادة قياسية للمقارنة. الكلمات المفتاحية: السيفالوسبورين، السيفالوكسين، كلايسين، الالنين، فالين والبرولين.

Introduction

The wide use of antibiotics in man and animals and their extensive use in areas other than the treatment and prophylaxis of diseases have resulted in a serious problem of drug resistance. More and more bacterial strains have become resistant to available drugs. A relation between the structure of the complexes and their anti-bacterial activity can be observed⁽¹⁾.

In the last two decades, antimicrobial resistance has become one of the greatest health problems, mainly in hospitals⁽²⁾.

Despite the continuous development and introduction of new antibiotics, resistance continues to increase progressively in several microbes⁽³⁾. Preparation of different semisynthetic derivatives of cephalosporins based on structure-activity relationship has been one of the best approaches. Intensive search for new cephalosporins that may have broader antibacterial spectrum and resistance toward β -lactamase-producing bacteria and could be used orally are of great interest⁽⁴⁾. Cephalixin is a β -lactam antibacterial and has bactericidal action and acts similarly to

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benzyl penicillin by inhibiting synthesis of the bacterial cell wall. It is most active against G (+) cocci and has moderate activity against some G (-) bacilli. Sensitive G (+) cocci includes both penicillinase- and non-penicillinase-producing *staphylococci*, although methicillin-resistant *staphylococci* are resistant; most *streptococci* are also sensitive, but not penicillin-resistant *Streptococci Pneumoniae*; *Enterococci*, which are usually resistant. Some G (+) anaerobes are also susceptible. Cephalixin is usually inactive against *Listeria monocytogenes*. Among G (-) bacteria, cephalixin has activity against some *Enterobacteriaceae* including strains of *E. coli*, *K. pneumoniae*, *Proteus mirabilis*, *Salmonella* and *Shigella spp.*, but not active against *Enterobacter*, indole-positive *Proteus* and *Serratia spp.* It is also active against *Moraxella catarrhalis* (*Branhamella catarrhalis*) and *Neisseria spp.*, though *Haemophilus influenzae* is moderately resistant. *Bacteroides fragilis* and *P. aeruginosa* are not sensitive and neither, *mycobacteria*, *mycoplasma* nor fungi⁽⁵⁾. The incorporation of privileged chemical moieties, such as, amino acids has been found to have great potential in the field of antimicrobial agents. Amino acid linked to cephalixin through amide bond can be of great benefits and may add appreciable activity, resistance to β -lactamases and/ or improved pharmacokinetic properties. The proposed compounds may serve for injectable purposes, when prepared as sodium salt or could be used orally due to expected stability in aqueous acidic condition due to the presence of primary amine group at the α -carbon of the acyl side chain.

Experimental Work

Materials and Methods

General

Melting points (uncorrected) were determined using electrical melting point apparatus, Electro-thermal 9300, USA. The infrared spectra were performed in KBr disc by FT-IR spectrophotometer/ Shimadzu. Elemental micro-analyses (CHN) were performed by Euro-vector EA 3000A, Italy. Checking the purity of the products as well as monitoring the progress of the reaction was achieved by Thin layer chromatography using Silica gel F₂₅₄ aluminum sheets, Merck, Germany.

Chemicals and Reagents

Ethyl chloroformate (ECF) was purchased from Sigma Aldrich/ Germany, Boc- glycine; Boc-L-alanine, Boc-L-valine and Boc-L-proline were purchased from Shanghai World Yang Chemical/China. Trifluoroacetic acid (TFA) was obtained from Sigma

Aldrich/Germany. Cephalixin monohydrate was from SDI Samarra/Iraq

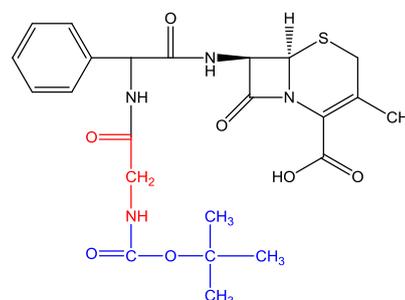
General procedure for synthesis of the intermediates of cephalixin (1a-d).

The new intermediates of cephalixin were synthesized by the mixed anhydride method⁽⁷⁻⁹⁾, as shown in (schemes 1 and 2).

Boc-amino acid (11.41 mmol) was dissolved in Tetrahydrofuran, THF (20mL) containing TEA (11.41 mmol) and this mixture was cooled in an ice bath at (-10°C). Ethyl chloroformate, ECF (11.41 mmol) was added drop wise over a period of 10 min and the mixture was continuously stirred for further 30 min. Cephalixin (11.41 mmol) in distilled water (10ml), containing TEA (11.41 mmol) was cooled to 0 °C and added at once to the above solution and the mixture was stirred for 4 hrs at -10 °C and for 2 hrs at room temperature. The solvent was evaporated and the resultant precipitate was washed with diluted HCl (0.1N) and filtered. The precipitate was collected and was washed with water several times with stirring, then washed with ether, recrystallized from ethanol/ toluene (1:9).

Synthesis of 1a, 7-(2-(2-((t-butoxy carbonyl)-amino)acetamido)-2-phenylacetamido)-3-methyl-8-oxo-5-thia-1-azabicyclo {4.2.0}oct-2-ene-carboxylate

This compound **1a** was synthesized, as previously described and as shown in (scheme 1).

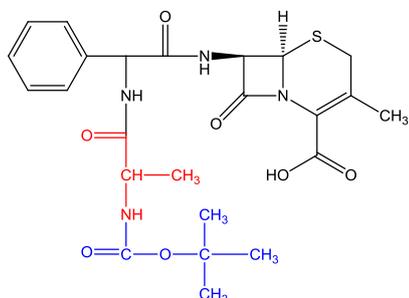


Chemical structure of compound 1a

Boc-glycine (11.416mmol, 5.75g) in THF (20mL) containing TEA (11.416 mmol, 1.153 g) was reacted with ECF (11.416 mmol, 1.24 g). Cephalixin (11.416 mmol, 4.16 g) in distilled water (10ml) containing TEA (11.416 mmol, 1.153 g) was added. The reaction mixture was treated as described earlier. The physical appearance, percent yield and R_f value are listed on table (1).

Synthesis of 1b, 7-(2-2-((*t*-butoxy carbonyl amino) propanamido)-2-phenylacetamido)-3-methyl-8-oxo-5-thia-1-azabicyclo {4.2.0} oct-2-ene-carboxylate

This compound **1b** was synthesized, as follows and as shown in (scheme 1):

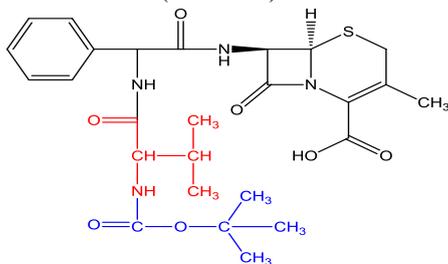


Chemical structure of compound 1b

BOC-alanine (11.416 mmol, 5.91 g) in 20 ml of THF containing TEA (11.416 mmol, 1.153g) was reacted with ECF (11.416 mmol, 1.24 g). Cephalixin (11.416mmol, 4.16 g) in distilled water (10ml) containing TEA (11.416 mmol, 1.153g) was added. The reaction mixture was treated as previously described. The physical appearance, percent yield and R_f value are listed on table (1).

Synthesis of 1c, 7-(2-2- ((*t*-butoxy carbonyl amino)-3-methylbutanamido)-2-phenyl acetamido)-3-methyl-8-oxo-5-thia-1-azabicyclo {4.2.0} oct-2-ene carboxylate

Compound **1c** was synthesized, as follows and as shown in (scheme 1):

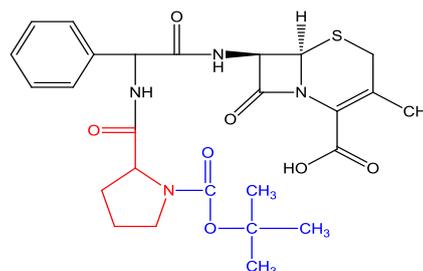


Chemical structure of compound 1c

Boc-valine (11.416 mmol, 6.23 g) in 20 ml of THF containing TEA (11.416 mmol, 1.153g) reacted with ECF (11.416 mmol, 1.24g). Cephalixin (11.416 mmol, 4.16 g) in distilled water (10ml) containing TEA (11.416 mmol, 1.153g) was added. The mixture was treated as previously described. The physical appearance, percent yield and R_f value are listed on table (1).

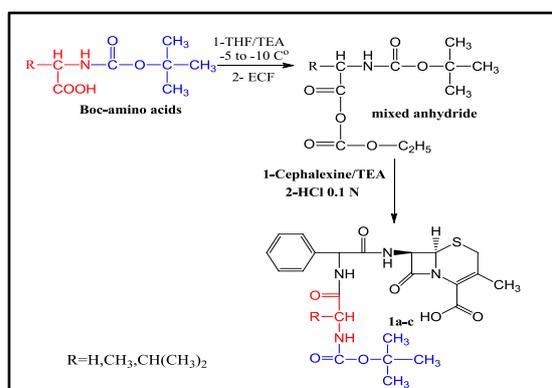
Synthesis of 1d, 7-(2-(1-(*t*-butoxy carbonyl) pyrrolidin-2-carboxamido)-2-phenylacetamido)-3-methyl-8-oxo-5-thia-1-azabicyclo {4.2.0} oct-2-ene-carboxylate.

Compound **1d** was synthesized, as follows and as shown in (scheme 2):

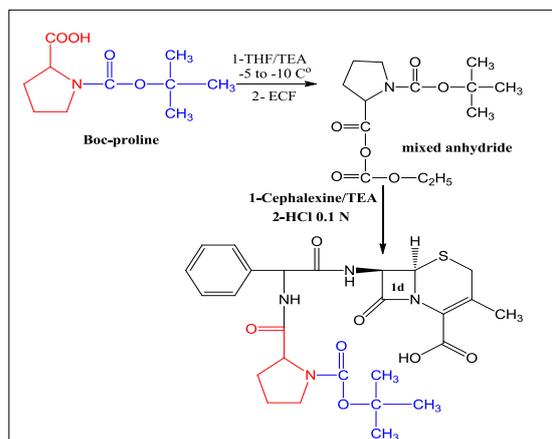


Chemical structure of compound 1d

Boc-proline (11.416mmol, 6.22g) in THF (20ml) containing TEA (11.416 mmol, 1.153g) was reacted with ECF (11.416mmol, 1.24g). Cephalixin (11.416 mmol, 4.16 g) in distilled water (10ml) containing TEA (11.416 mmol, 1.153g) was added. The mixture was treated as previously described. The physical appearance, percent yield and R_f value are listed on table (1).



Scheme (1): Synthesis of intermediates 1a-c



Scheme (2): Synthesis of intermediate 1d

General procedure for synthesis of the new derivatives of cephalixin (1-4).

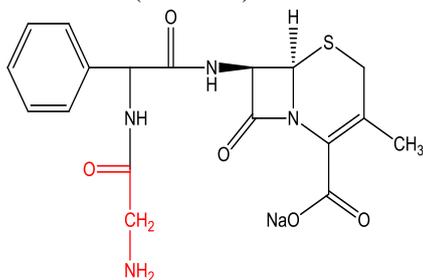
These compounds were obtained by deprotection⁽¹⁰⁾ of the amino group of compounds **1a-d**, to afford the new derivatives of cephalixin 1-4, as follows and as shown in (schemes 3 and 4).

Compounds **1a-d**, (1.984 mmol) was suspended in dichloromethane (DCM) (10ml) and cooled

to 0 °C in an ice bath and TFA (15ml) was added with continuous stirring for 1hr at 0°C in presence of anisole (3ml). The completion of the reaction was monitored by TLC using the mobile phase methanol: chloroform (1:1). Diethyl ether (100ml) was added to the reaction mixture and the resulting precipitate was collected, suspended in methanol (30) ml and the pH was adjusted to 7 with 5% methanolic solution of NaOH. A precipitate was formed after the addition of ether, which was filtered and washed with acetone and recrystallized from ethyl acetate: petroleum ether (9:1). The precipitate was collected and dried in an oven at 50°C.

Synthesis of 1, 7-(2-(2-aminoacetamido)-2-phenylacetamido)-3-methyl-8-oxo-5-thia-1-azabicyclo{4.2.0}oct-2-ene-carboxylate Sodium.

Compound **1** was obtained by deprotection of the amino group of compound **1a**, as follows and as shown in (scheme 3):

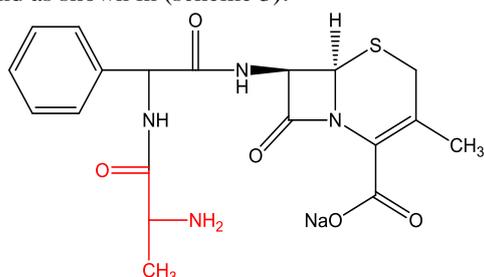


Chemical structure of compound 1

Compound **1a** (1.984 mmol, 1 g) in DCM (10ml) was reacted with TFA (15ml) in presence of anisole (3ml). The mixture was treated as previously described. A yellowish crystalline powder was collected. The physical appearance, percent yield and R_f value are listed on table (1).

Synthesis of 2, 7-(2-(2-amino propan amido)2-phenylacetamido)-3-methyl-8-oxo-5-thia-1-azabicyclo{4.2.0}oct-2-ene-carboxylate Sodium.

Compound **2** was obtained by deprotection of the amino group of compound **1b**, as follows and as shown in (scheme 3):

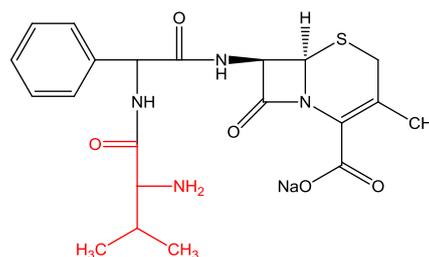


Chemical structure of compound 2

Compound **1b** (1.984mmol, 1.027 g) in DCM (10ml) was reacted with TFA (15ml) in presence of anisole (3ml). The mixture was treated as previously described. The physical appearance, percent yield and R_f value are listed on table (1).

Synthesis of 3, 7- (2- (2-amino-3-methylbutan amido) 2-phenylacetamido)-3-methyl-8-oxo -5-thia-1-azabicyclo {4.2.0}oct-2-ene-carboxylate Sodium.

Compound **3** was obtained by deprotection of the amino group of compound **1c**, as follows and as shown in (scheme 3):

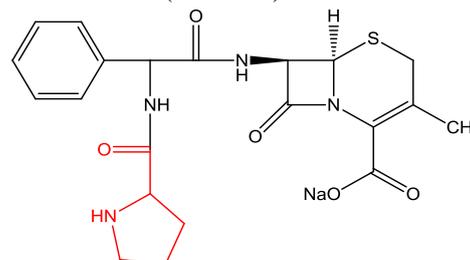


Chemical structure of compound 3

Compound **1c** (1.984 mmol, 1.083 g) in DCM (10ml) was reacted with TFA (15ml) in the presence of anisole (3ml) and the mixture was treated as previously described. The physical appearance, percent yield and R_f value are listed on table (1).

Synthesis of 4, 7-(2-phenyl-2- (pyrrolidin -2 -carboxamido) acetamido)-5-thia-1-azabicyclo {4.2.0} oct - 2 - ene-carboxylate Sodium.

Compound **4** was obtained by deprotection of the amino group of compound **1d**, as follows and as shown in (scheme 4):

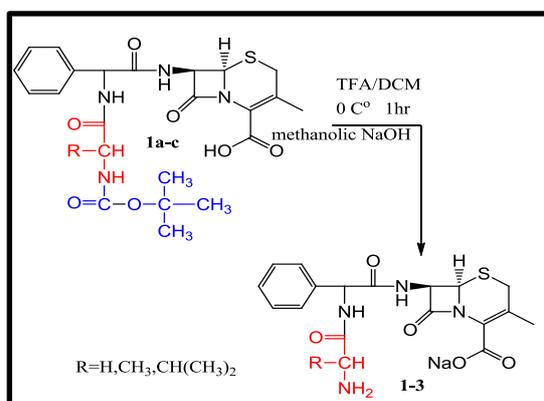


Chemical structure of compound 4

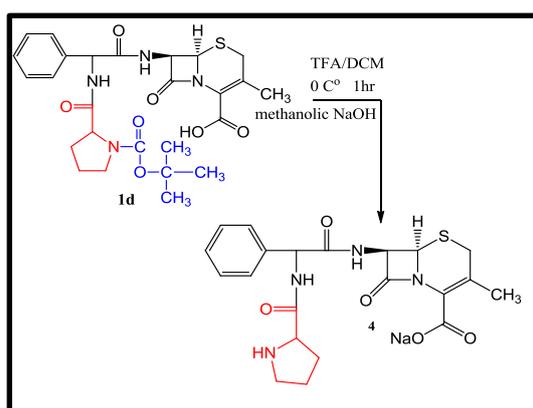
Compound **1d** (1.984 mmol, 1.081 g) in DCM (10ml) was reacted with TFA (15) in presence of anisole (3ml) and the mixture was treated as previously described. The physical appearance, percent yield and R_f value are listed in table (1).

Table (1): Physical parameters and percent yields of the synthesized compounds.

Compound	Physical appearance	% Yield	m.p. (°C)	R _f value
1a	White	63.8	172-177	0.60 (A)
1b	White	72	182-186	0.44 (A)
1c	White	74	160-166	0.55 (A)
1d	Off white	82	180-185	0.50 (A)
1	Pale yellow	95	185 (decomposed)	0.41 (B)
2	Pale yellow	44	200 (decomposed)	0.46 (B)
3	Off white	70	214 (decomposed)	0.57(B)
4	Off white	40	212 (decomposed)	0.55(B)
Cephalexin	Off white	--	182-186	0.11(A)



Scheme (3): Synthesis of the target compounds 1-3



Scheme (4): Synthesis of the target compound 4

Results and Discussion

The use of two solvent systems A and B was to differentiate between reactants and products and to follow progress of reactions. A-Chloroform: Methanol (3:1) B-Chloroform: Methanol (1:3), as illustrated on Table (1).

The IR characteristic bands of compound **1** are 1543, 1400 (C=O stretching of carboxylate anion), 3060 (N-H stretching 2-amide), 3473, 3397 (N-H stretching of primary amine group), 1656 (C=O stretching 2-amide), 1761 (C=O stretching β-lactam), 1543 (N-H bending 2-amide). The elemental analysis (CHN) was calculated for C₁₈H₁₉N₄SO₅Na (426); calculated: C; 50.70, H; 4.46, N; 13.145. Found C; 48.35, H; 4.684, N; 13.36.

The IR characteristic bands of compound **2** are 1549, 1400 (C=O stretching of carboxylate anion), 3061 (N-H stretching 2-amide), 3494, 3399 (N-H stretching primary amine group), 1664 (C=O stretching 2-amide), 1759 (C=O stretching β-lactam), 1527 (N-H bending 2-amide). CHN analysis was calculated for C₁₉H₂₁N₄SO₅Na (440); calculated C: 51.8, H: 4.77, N: 12.72. Found C: 49.91, H: 4.56, N: 12.28.

The IR characteristic bands of compound **3** are as follows; 1543, 1400 C=O stretching of carboxylate anion, 3063 (N-H stretching of 2-amide), 3473, 3397 (N-H stretching of primary amine), 1653 (C=O stretching of 2-amide), 1759 (C=O stretching of β-lactam), 1570 (N-H bending of 2-amide). CHN analysis was calculated for C₂₁H₂₅N₄SO₄Na (429) calculated; C: 53.846, H: 5.341, N: 11.965. Found C: 52.04, H: 5.16, N: 11.71.

The IR characteristic bands of compound **4** are 1550, 1400 C=O stretching of carboxylate anion, 3034.13N-H stretching of 2-amide, 3373, 3317 N-H stretching of primary amine group, 1662.69 C=O stretching of 2-amide, 1755.28 C=O stretching of β -lactam, 1527 N-H bending of 2-amide. CHN analysis was calculated for $C_{21}H_{25}N_4SO_5Na$ (445), calculated; C: 54.663, H: 3.904, N: 12.147. Found C: 52.20, H: 3.78, N: 12.68.

Preliminary Antimicrobial Evaluation

The synthesized compounds were subjected to antimicrobial evaluation by well-diffusion method⁽¹¹⁾. The zone of inhibition (mm) was measured in comparison with cephalixin. The

antimicrobial activity was performed in nutrient agar medium containing *E. coli*, *P. aeruginosa* and *Bacillus cereus*, *S. aureus* and the compounds used at concentrations (125 and 250 μ g/well). The activity was determined after incubation for 24h at 37°C by the comparison of inhibition of growth of bacteria by cephalixin using dimethyl sulfoxide (DMSO) as the solvent. No inhibition zone was observed for the control (dimethylsulfoxide). These compounds were subjected to preliminary antimicrobial evaluation against four types of microbes (*E. coli*, *P. aeruginosa*, and *Bacillus cereus*, *S. aureus*).

Table (2) :The preliminary antibacterial activity of the new derivatives of cephalixin.

Compound	Concentration μ g/ml	Escherichia coli.	Pseudomonas aeruginosa	Staphylococcus aureus	Bacillus cereus.
DMSO	--	9	-	10	-
cephalexin	125	10	-	12	-
	250	12		14	
1	125	-	11	-	-
	250	-	12	-	-
2	125	-	11	-	6
	250	-	14	8	10
3	125	8	15	9	15
	250	9	15	9	17
4	125	-	-	-	-

Key to symbols: (-) = no inhibition.

The antimicrobial evaluation revealed that the newly synthesized compounds, **1-4** showed reasonable antibacterial activities against G (-) bacteria, such as *P. aeruginosa* and G (+) bacteria, such as *Bacillus cereus* in comparison with cephalixin, which has no activity against these type of microbes.

Compound **1** (125 and 250 μ g) showed significant activity against *P. aeruginosa* and reduction in antibacterial activities against *S. aureus* and *E. coli* as compared with cephalixin. Compound **2** (125 μ g, 250 μ g) showed significant activity against *P. aeruginosa* and *Bacillus cereus*, as compared with cephalixin. Furthermore, at concentration (125 μ g) compound **2** exhibited no activity against *S. aureus* and *E. coli*. However, at concentration of (250 μ g) the activity was less against *S. aureus* as compared with cephalixin. Compound **3** (125 and 250 μ g) showed very significant activity against *E. coli*, *P. aeruginosa* and *Bacillus cereus* and slight activity towards *S. aureus*. This result indicates that compound **3** has a broader spectrum of antibacterial activities, i.e. against both G (+) and G (-) bacteria.

Compound **4** (125 μ g) has no antibacterial activities against all strains of bacteria used. However, Compound **4** at concentration (250 μ g) showed significant activity against *P. aeruginosa* and no antibacterial activities against *E. coli*, *S. aureus* and *Bacillus cereus* as compared with cephalixin. This chemical modification at the acyl side chain positioned at alpha to β -lactam ring supposed to provide some protection against β -lactamses. This model contains a primary amino group of the amino acid, which may provide certain stability in the acidic condition of stomach⁽⁴⁾.

Conclusion

A series of new derivatives of cephalixin have been synthesized successfully in appreciable yields and screened for their antimicrobial activity using well diffusion method against bacterial strains (*E. coli*, *P. aeruginosa* and *Bacillus cereus*, *S. aureus*). It is concluded that the new derivatives of cephalixin linked with certain amino acids were found to possess moderate antibacterial activities. Furthermore, the new derivative of cephalixin linked with valine has a significant activity against *p. aeruginosa* and *Bacillus cereus*.

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