1,3,4-OXADIAZOLE AND 1,3,4-THIADIAZOLE β-LACTAMASE INHIBITORS

RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 61/618,131, filed March 30, 2012, and U.S. Provisional Application No. 61/790,579, filed March 15, 2013. The entire contents of these applications are incorporated herein by reference in their entireties.

TECHNICAL FIELD

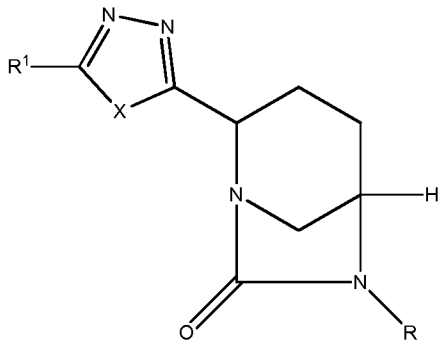
This disclosure is directed to β-lactamase inhibitors (BLIs) which are effective as inhibitors of β-lactamases and, when used in combination with β-lactam antibiotics are useful in the treatment of bacterial infections. The compounds when combined with a β-lactam antibiotic are effective in treating infections caused by bacteria that are resistant to β-lactam antibiotics due to the presence of β-lactamases. Pharmaceutical compositions comprising such compounds, methods of using such compounds, and processes for preparing such compounds are also disclosed.

BACKGROUND

Bacterial resistance to β-lactam antibiotics, especially in Gram-negative bacteria, is most commonly mediated by β-lactamases. β-lactamases are enzymes that catalyze the hydrolysis of the β-lactam ring, which inactivates the antibacterial activity of the β-lactam antibiotic and allows the bacteria to become resistant. Inhibition of the β-lactamase with a BLI slows or prevents degradation of the β-lactam antibiotic and restores β-lactam antibiotic susceptibility to β-lactamase producing bacteria. Many of these β-lactamases are not effectively inhibited by BLIs currently on the market rendering the β-lactam antibiotics ineffective in treating bacteria that produce these β-lactamases. There is an urgent need for novel BLIs that inhibit β-lactamases that are not effectively inhibited by the current clinical BLIs (e.g. KPC, class C and class D β-lactamases) and that could be used in combination with β-lactam antibiotics to treat infections caused by β-lactam resistant bacteria.

SUMMARY OF INVENTION

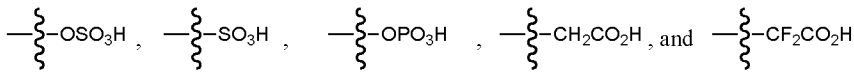
The present invention provides, in one aspect, compounds of chemical formula (I), or pharmaceutically-acceptable salts thereof, which are BLIs and are useful in combination with β-lactam antibiotics for the treatment of bacterial infections.



(I)

wherein X is selected from O and S;

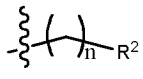
R is selected from



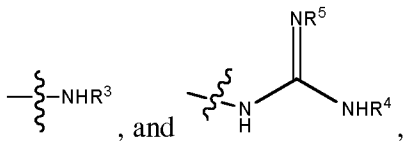
and,

R^1 is selected from:

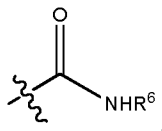
a. hydrogen;

b. ,

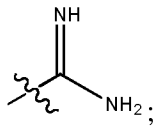
wherein R^2 is selected from



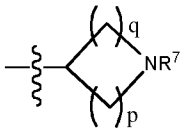
wherein each of R^3, R^4 and R^5 is independently selected from hydrogen, (C_1-C_3)-alkyl, aminoalkyl, aminocycloalkyl, and hydroxyalkyl, and n is selected from 1, 2 and 3;

c. ,

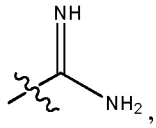
wherein R^6 is H, (C_2-C_3) alkylamino, and

;

d. amino;

e. ,

wherein R^7 is selected from H, (C_1-C_3)-unsubstituted alkyl, amino-(C_2-C_3)-alkyl, aminocycloalkyl, hydroxyalkyl,



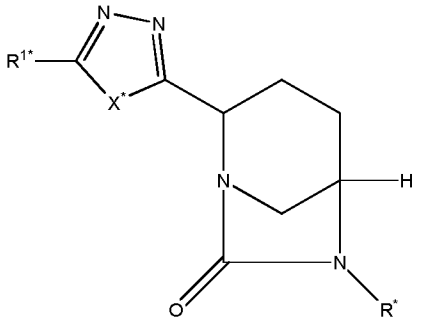
and

and each of p and q is independently selected from 1 and 2; and

f. $-CH(R^8)CH_2NH_2$

wherein R^8 is selected from amino and hydroxyl.

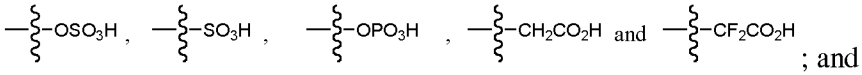
In another aspect, the invention provides compounds of chemical Formula (A-I) or a pharmaceutically acceptable salt thereof, which are BLIs and are useful in combination with β-lactam antibiotics for the treatment of bacterial infections.



(A-I)

wherein X* is selected from O and S;

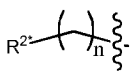
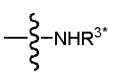
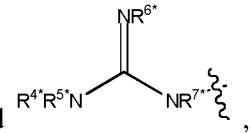
R* is selected from

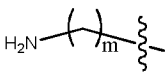
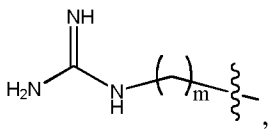


; and

R^{1*} is selected from:

a. hydrogen;

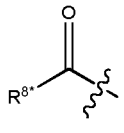
b. ,wherein R^{2*} is selected from , and ,

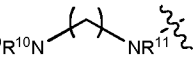
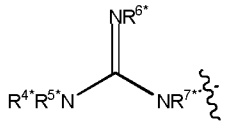
R^{3*} is selected from hydrogen, (C_1-C_3)-alkyl, aminoalkyl, aminocycloalkyl, hydroxyalkyl,  and ,

each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is independently selected from hydrogen or (C_1-C_6)-alkyl, aminoalkyl, aminocycloalkyl, and hydroxyalkyl, provided that at least one of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is hydrogen,

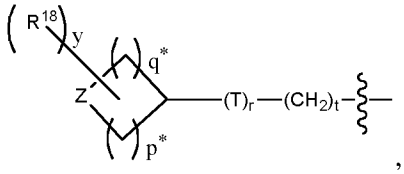
n is selected from 1, 2, 3 and 4, and

m is selected from 1, 2 and 3;

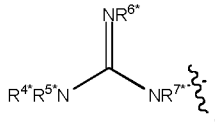
c. ,

wherein R^{8*} is selected from NH_2,  or ,wherein each of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is as described previously and each of R^9, R^{10}, and R^{11} is independently selected from hydrogen or (C_1-C_6)-alkyl, provided that at least one of R^9, R^{10}, and R^{11} is hydrogen;

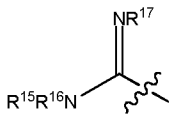
d. amino;

e. ,

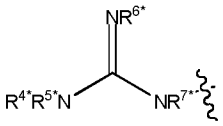
wherein Z is selected from $CR^{12}R^{13}$ or NR^{14},

each of R^{12} and R^{13} is independently selected from H, NH_2 and , wherein each of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is as described previously,

alternatively, R^{12} and R^{13} together with the carbon to which they are attached, form a cycloalkyl or heterocyclyl ring containing 4-6 ring members,

R^{14} is selected from H and , wherein each of R^{15}, R^{16} and R^{17} is independently selected from hydrogen, (C_1-C_6)-alkyl, aminoalkyl,

aminocycloalkyl, and hydroxyalkyl, provided that at least one of R^{15}, R^{16} and R^{17} is hydrogen,

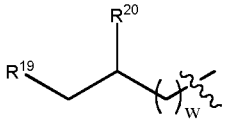
R^{18} is selected from NH_2 and , wherein each of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is as described previously,

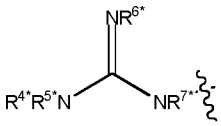
each of p* and q* is independently selected from 0, 1, 2 and 3,

T is selected from NH and O

t is selected from 0, 1, 2, 3, and 4, and

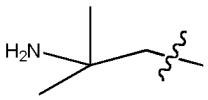
each of r and y is independently selected from 0 and 1;

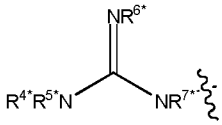
f. ,

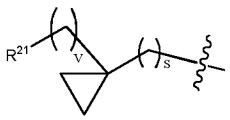
wherein R^{19} is selected from NH_2 and , wherein each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is as described previously,

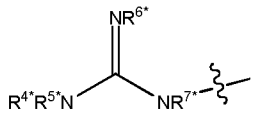
R^{20} is selected from amino and hydroxyl, and

w is selected from 0 and 1;

g. ;

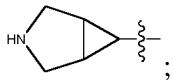
h. , wherein each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is as described previously;

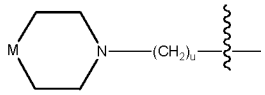
i. ;

wherein R^{21} is selected from NH_2, -NH(C_1-C_3)-alkyl and , wherein each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is as described previously,

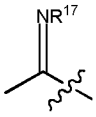
s is selected from 0 and 1, and

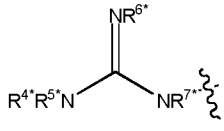
v is selected from 0, 1, 2, and 3;

j.  ;

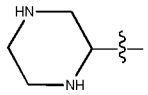
k.  ,

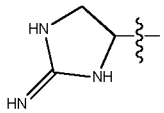
wherein M is selected from NR^{22}, $CR^{23}R^{24}$ and O,

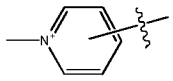
wherein R^{22} is H or  , wherein each of R^{15}, R^{16} and R^{17} is as described previously,

each of R^{23} and R^{24} is independently selected from H, NH_2 and  wherein each of R^{4*}, R^{5*}, R^{6*} and R^{7*} is as described previously, and

u is selected from 0, 1 and 2;

l.  ;

m.  ; and

n.  .

In one embodiment, the invention provides use of a compound of Formula I for inhibiting β-lactamases.

In one embodiment, the invention provides use of a compound of Formula A-I for inhibiting β-lactamases.

In one embodiment, the invention provides compounds of Formula I with high binding affinity for β-lactamase enzymes.

In one embodiment, the invention provides compounds of Formula A-I with high binding affinity for β-lactamase enzymes.

In one embodiment, the present invention also provides antibacterial compositions comprising compounds of Formula I and at least one β-lactam antibiotic.

In one embodiment, the present invention also provides antibacterial compositions comprising compounds of Formula A-I and at least one β-lactam antibiotic.

In one embodiment, the present invention provides pharmaceutical compositions comprising compounds of Formula I and at least one β-lactam antibiotic and methods of use thereof.

In one embodiment, the present invention provides pharmaceutical compositions comprising compounds of Formula A-I and at least one β-lactam antibiotic and methods of use thereof.

In one embodiment, the invention provides methods of use of the compounds of Formula I to treat bacterial infections in a subject.

In one embodiment, the invention provides methods of use of the compounds of Formula A-I to treat bacterial infections in a subject.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A-1I show Table I, Representative Compounds of Formula A-II

Figures 2A-2G show Table II, Standard BLI potentiation MIC assay against a panel of isogenic and clinical strains expressing β-lactamases.

Figures 3A-3F show Table III, the synergy MIC of representative compounds of Formula II-A against a panel of isogenic and clinical strains expressing β-lactamases.

Figures 4A-4C show Table IV, an assay to determine inhibition kinetics of representative compounds of Formula II-A for the KPC-2 β-lactamase.

Figures 5A-5B show Table V, Synergy MICof Comparator Compounds Against a Panel of Isogenic and Clinical Strains Expressing β-lactamases

Figure 6 shows Table VI, Standard BLI Potentiation MIC Assay of Compounds Partnered with CXA-101 Against a Panel of Isogenic and Clinical Strains Expressing β-Lactamases

Figure 7 shows Table VII, Standard BLI Potentiation MIC Assay of Compounds Partnered with Ceftazidime Against a Panel of Isogenic and Clinical Strains Expressing β-Lactamases

Figure 8 shows Table VIII, Standard BLI Potentiation MIC Assay of Compounds Partnered with Aztreonam Against a Panel of Isogenic and Clinical Strains Expressing β-Lactamases

Figure 9 shows Table IX, Standard BLI Potentiation MIC Assay of Compounds Partnered with Meropenem Against a Panel of Isogenic and Clinical Strains Expressing β-Lactamases

DETAILED DESCRIPTION

Definitions:

Molecular terms, when used in this application, have their common meaning unless otherwise specified.

The term "alkyl" is defined as a linear or branched, saturated radical having one to about twenty carbon atoms unless otherwise specified. Preferred alkyl radicals are "lower alkyl" radicals having one to about five carbon atoms. Examples of alkyl groups include, without limitation, methyl, ethyl, *tert*-butyl, isopropyl, and hexyl. A subset of the term alkyl is "(C_1-C_3)-unsubstituted alkyl" which is defined as an alkyl group that bears no substituent groups. Examples of (C_1-C_3)-unsubstituted alkyl groups include methyl, ethyl, propyl and isopropyl. It is understood that if a (C_1-C_3)-alkyl is "substituted" that one or more hydrogen atoms is replaced by a substitutent.

The term amino denotes a NH_2 radical.

The term "aminoalkyl" denotes an alkyl in which one or more of the alkyl hydrogen atoms has been replaced by an amino group.

The term "aminocycloalkyl" denotes a cycloalkyl in which one of the cycloalkyl hydrogen atoms has been replaced by an amino group.

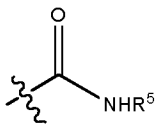
The term "cycloalkyl" or "cycloalkyl ring" is defined as a saturated or partially unsaturated carbocyclic ring in a single or fused carbocyclic ring system having from three to twelve ring members. In a preferred embodiment, a cycloalkyl is a ring system having three to seven ring members. Examples of a cycloalkyl group include, without limitation, cyclopropyl, cyclobutyl, cyclohexyl, and cycloheptyl.

The term "hydroxyalkyl" denotes an alkyl radical in which one or more of the alkyl hydrogen atoms has been replaced by a hydroxyl group.

It will be understood by one of skill in the art that a


or –

denote the point of attachment of a substituent group where indicated. For example



or–C(O)NHR^5

represent that the point of attachment of the amide moiety is at the carbonyl carbon.

The functional classification of β-lactamases and terms "Class A", "Class C", and "Class D" β-lactamases are understood by one of skill in the art and are described in "Updated Functinal Classification of β-Lactamases", Bush, K.; Jacoby, G. A.; *Antimicrob. Agents Chemother.* **2010,** *54*, 969-976, herein incorporated by reference.

The salts of the compounds of the invention include acid addition salts and base addition salts. In a one embodiment, the salt is a pharmaceutically acceptable salt of the compound of Formula I. The term "pharmaceutically acceptable salts" embraces salts commonly used to form alkali metal salts and to form addition salts of free acids or free bases. The nature of the salt is not critical, provided that it is pharmaceutically-acceptable. Suitable pharmaceutically acceptable acid addition salts of the compounds of the invention may be prepared from an inorganic acid or an organic acid. Examples of such inorganic acids include, without limitation, hydrochloric, hydrobromic, hydroiodic, nitric, carbonic, sulfuric and phosphoric acid. Examples of appropriate organic acids may be selected from aliphatic, cycloaliphatic, aromatic, arylaliphatic, heterocyclic, carboxylic and sulfonic classes of organic acids, examples of which include, without limitation, formic, acetic, propionic, succinic, glycolic, gluconic, maleic, embonic (pamoic), methanesulfonic, ethanesulfonic, 2-hydroxyethanesulfonic, pantothenic, benzenesulfonic, toluenesulfonic, sulfanilic, mesylic, cyclohexylaminosulfonic, stearic, algenic, ß-hydroxybutyric, malonic, galactic, and galacturonic acid. Suitable pharmaceutically-acceptable base addition salts of compounds of the invention include, but are not limited to, metallic salts made from aluminum, calcium, lithium, magnesium, potassium, sodium and zinc or organic salts made from N,N'-dibenzylethylenediamine, chloroprocaine, choline, diethanolamine, ethylenediamine, N-methylglucamine, lysine and procaine. All of these salts may be prepared by conventional means from the corresponding compound of the invention by treating, for example, the compound of the invention with the appropriate acid or base.

The compounds of the invention can possess one or more asymmetric carbon atoms and are thus capable of existing in the form of optical isomers as well as in the form of racemic or non-racemic mixtures thereof. The compounds of the invention can be utilized in the present invention as a single isomer or as a mixture of stereochemical isomeric forms. Diastereoisomers, i.e., nonsuperimposable stereochemical isomers, can be separated by conventional means such as chromatography, distillation, crystallization or sublimation. The optical isomers can be obtained by resolution of the racemic mixtures according to

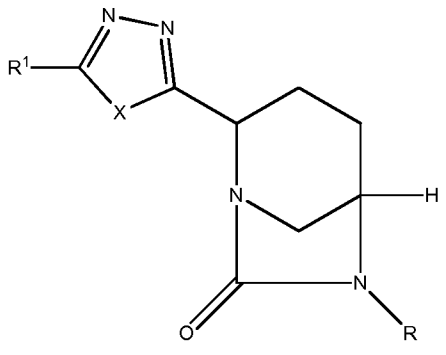
conventional processes, for example by formation of diastereoisomeric salts by treatment with an optically active acid or base. Examples of appropriate acids include, without limitation, tartaric, diacetyltartaric, dibenzoyltartaric, ditoluoyltartaric and camphorsulfonic acid. The mixture of diastereomers can be separated by crystallization followed by liberation of the optically active bases from the optically active salts. An alternative process for separation of optical isomers includes the use of a chiral chromatography column optimally chosen to maximize the separation of the enantiomers. Still another available method involves synthesis of covalent diastereoisomeric molecules by treating compounds of the invention with an optically pure acid in an activated form or an optically pure isocyanate. The synthesized diastereoisomers can be separated by conventional means such as chromatography, distillation, crystallization or sublimation, and then hydrolyzed to obtain the enantiomerically pure compound. The optically active compounds of the invention can likewise be obtained by utilizing optically active starting materials. These isomers may be in the form of a free acid, a free base, an ester or a salt.

Compounds described herein also include isotopically-labeled compounds wherein one or more atoms is replaced by an atom having the same atomic number, but an atomic mass or mass number different from the atomic mass or mass number usually found in nature. Examples of isotopes suitable for inclusion in the compounds described herein include and are not limited to ^{2}H, ^{3}H, ^{11}C, ^{13}C, ^{14}C, ^{36}Cl, ^{18}F, ^{123}I, ^{125}I, ^{13}N, ^{15}N, ^{15}O, ^{17}O, ^{18}O, ^{32}P, and ^{35}S. In one embodiment, isotopically-labeled compounds are useful in drug and/or substrate tissue distribution studies. In another embodiment, substitution with heavier isotopes such as deuterium affords greater metabolic stability (for example, increased *in vivo* half-life or reduced dosage requirements). In yet another embodiment, substitution with positron emitting isotopes, such as ^{11}C, ^{18}F, ^{15}O and ^{13}N, is useful in Positron Emission Topography (PET) studies for examining substrate receptor occupancy. Isotopically-labeled compounds are prepared by any suitable method or by processes using an appropriate isotopically-labeled reagent in place of the non-labeled reagent otherwise employed.

The invention also embraces isolated compounds. An isolated compound refers to a compound which represents at least 10%, such as at least 20%, such as at least 50% and further such as at least 80% of the compound present in the mixture. In one embodiment, the compound, a pharmaceutically acceptable salt thereof, or a pharmaceutical composition comprising the compound exhibits detectable (i.e. statistically significant) activity when tested in conventional biological assays such as those described herein.

β-Lactamase Inhibitors (BLIs)

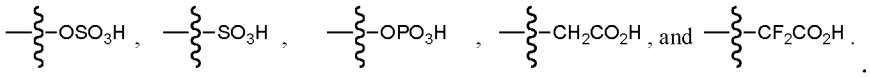
In one aspect, the invention provides compounds of Formula I or pharmaceutically-acceptable salts thereof:



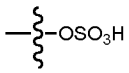
(I)

The substituent X of Formula I is selected from O and S. In one aspect of the invention X is S. In another aspect of the invention X is O.

Substituent R of Formula I is selected from

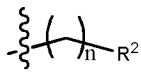


In a preferred embodiment, R is

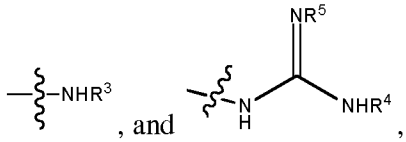


The group R^1 of Formula I is selected from:

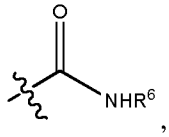
a. hydrogen;

b. ,

wherein R^2 is selected from

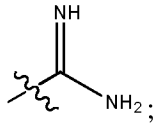


wherein each of R^3, R^4 and R^5 is independently selected from hydrogen, (C_1-C_3)-alkyl, aminoalkyl, aminocycloalkyl, and hydroxyalkyl, and n is selected from 1, 2 and 3;

c. 

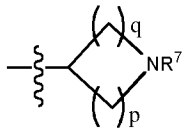
,

wherein R^6 is H, (C_2-C_3) alkylamino, and



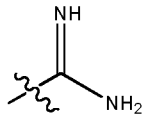
;

d. amino;

e. 

,

wherein R^7 is selected from H, (C_1-C_3)-unsubstituted alkyl, amino-(C_2-C_3)-alkyl, aminocycloalkyl, hydroxyalkyl,

and 

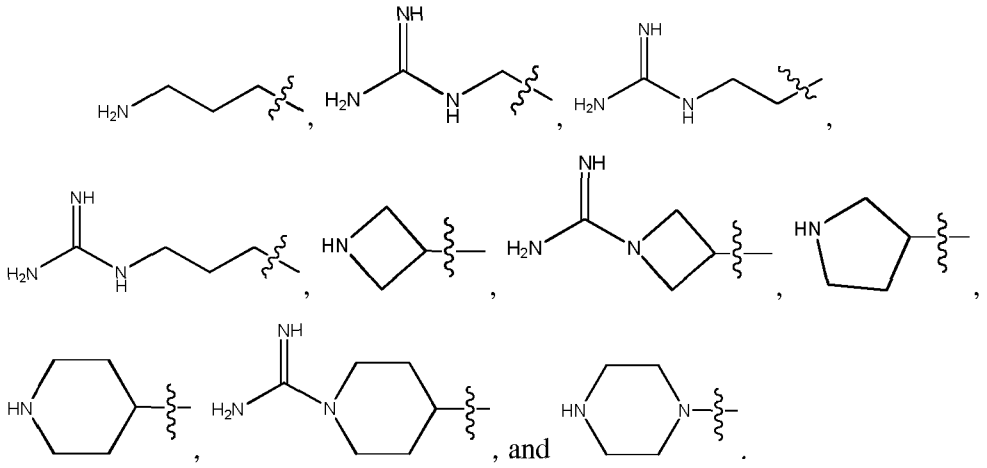
and each of p and q is independently selected from 1 and 2; and

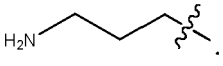
f. $-CH(R^8)CH_2NH_2$

wherein R^8 is selected from amino and hydroxyl.

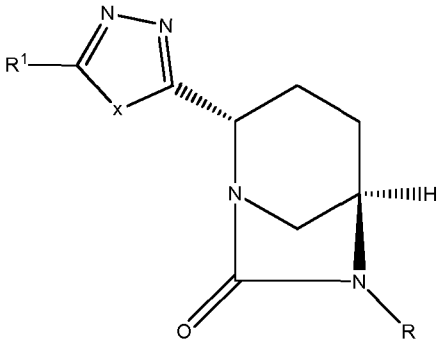
In one aspect of the invention n is 1. In another aspect of the invention n is 2. In another aspect of the invention n is 3.

In one aspect of the invention R^1 is selected from H, $-CH_2NH_2$, $-CH_2CH_2NH_2$, $-CONH_2$, $-NH_2$, $-CH(OH)CH_2NH_2$, $-CH(NH_2)CH_2NH_2$, $-CH_2CH_2NHCH_2CH_2NH_2$,



In one embodiment of the invention R^1 is selected from H and .

In one embodiment of the invention, the compounds of the invention are of the stereochemistry disclosed in Formula II.

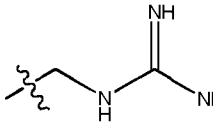


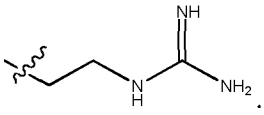
(II)

In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is H.

In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is $-CH_2NH_2$.

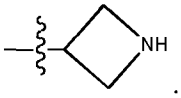
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is $-CH_2CH_2NH_2$.

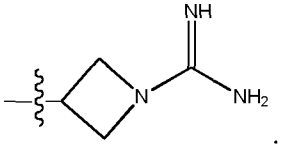
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is .

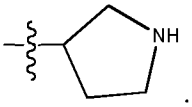
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is .

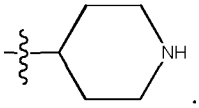
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is $-CONH_2$.

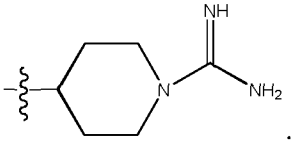
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is $-NH_2$.

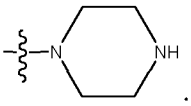
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is .

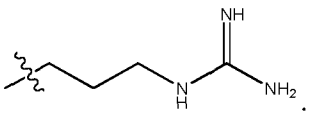
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is .

In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is .

In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is .

In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is .

In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is .

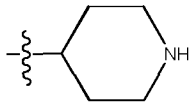
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is .

In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is $-CH(OH)CH_2NH_2$.

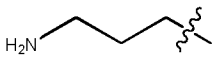
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is $-CH_2CH_2NHCH_2CH_2NH_2$.

In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is $-CH(NH_2)CH_2NH_2$.

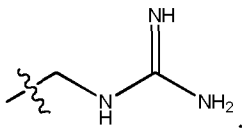
In another embodiment of the invention, the compound is of Formula II and X is S, R is $-OSO_3H$ and R^1 is $-CH_2CH_2NH_2$.

In another embodiment of the invention, the compound is of Formula II and X is S, R is $-OSO_3H$ and R^1 is 

.

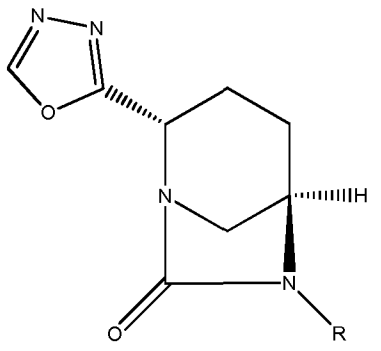
In another embodiment of the invention, the compound is of Formula II and X is O, R is $-OSO_3H$ and R^1 is 

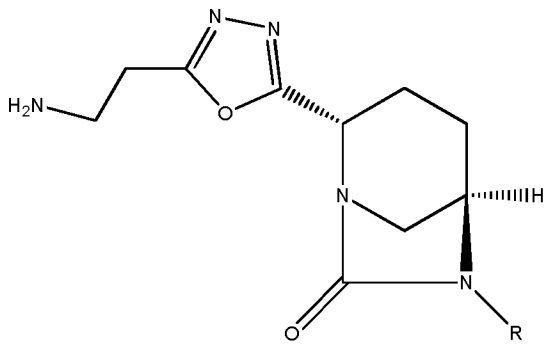
.

In another embodiment of the invention, the compound is of Formula and II X is S, R is $-OSO_3H$ and R^1 is 

.

Preferred compounds of Formula I are the compounds:

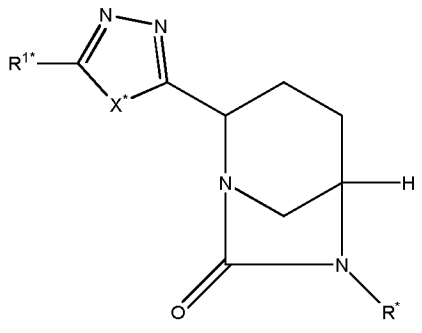


and


.

It will be understood by one of skill in the art that depending on the nature of R^1 and R, compounds of Formula I may exist in a salt or zwitterionic form.

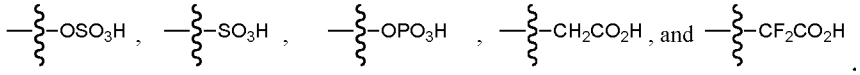
In one aspect, the invention provides compounds of Formula A-I or pharmaceutically-acceptable salts thereof:



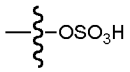
(A-I)

The substituent X^* of Formula A-I is selected from O and S. In one aspect of the invention X^* is S. In another aspect of the invention X^* is O.

Substituent R^* of Formula A-I is selected from

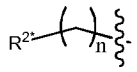


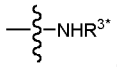
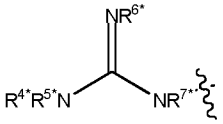
In a preferred embodiment, R^* is

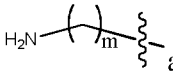
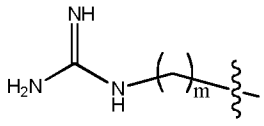


The group R^{1*} of Formula I is selected from:

a. hydrogen;

b. ,

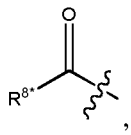
R^{2*} is selected from , and ,

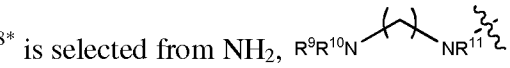
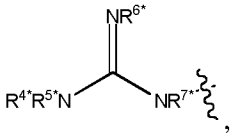
R^{3*} is selected from hydrogen, $(C_1\text{-}C_3)$-alkyl, aminoalkyl, aminocycloalkyl, hydroxyalkyl,  and ,

each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is independently selected from hydrogen or $(C_1\text{-}C_6)$-alkyl, aminoalkyl, aminocycloalkyl, and hydroxyalkyl, provided that at least one of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is hydrogen,

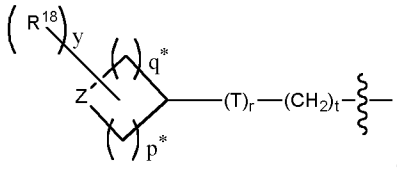
n is selected from 1, 2, 3 and 4, and

m is selected from 1, 2 and 3;

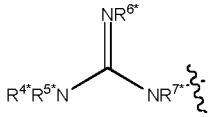
c. ,

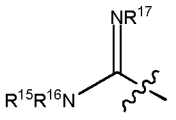
wherein R^{8*} is selected from NH_2,  or , wherein each of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is as described previously and each of R^9, R^{10}, and R^{11} is independently selected from hydrogen or $(C_1\text{-}C_6)$-alkyl, provided that at least one of R^9, R^{10}, and R^{11} is hydrogen;

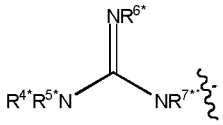
d. amino;

e. ,

Z is selected from $CR^{12}R^{13}$ or NR^{14},

each of R^{12} and R^{13} is independently selected from H, NH_2 and , wherein each of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is as described previously, alternatively, R^{12} and R^{13} together with the carbon to which they are attached, form a cycloalkyl or heterocyclyl ring containing 4-6 ring members,

R^{14} is selected from H and , each of R^{15}, R^{16} and R^{17} is independently selected from hydrogen, $(C_1\text{-}C_6)$-alkyl, aminoalkyl, aminocycloalkyl, and hydroxyalkyl, provided that at least one of R^{15}, R^{16} and R^{17} is hydrogen,

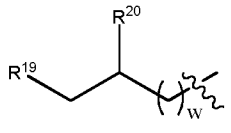
R^{18} is selected from NH_2 and , wherein each of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is as described previously,

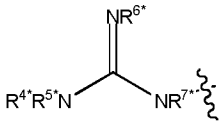
each of p* and q* is independently selected from 0, 1, 2 and 3,

T is selected from NH and O

t is selected from 0, 1, 2, 3, and 4, and

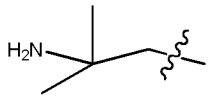
each of r and y is independently selected from 0 and 1;

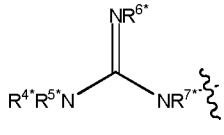
f. ,

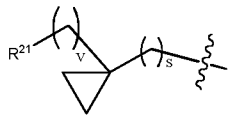
wherein R^{19} is selected from NH_2 and , wherein each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is as described previously,

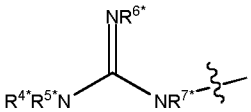
R^{20} is selected from amino and hydroxyl, and

w is selected from 0 and 1;

g. ;

h. , wherein each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is as described previously;

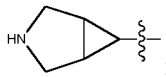
i. ;

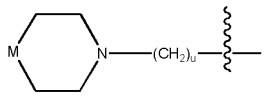
wherein R^{21} is selected from NH_2, -NH(C_1-C_3)-alkyl and ,

wherein each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is as described previously,

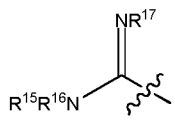
s is selected from 0 and 1, and

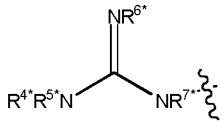
v is selected from 0, 1, 2, and 3;

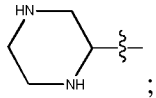
j. ;

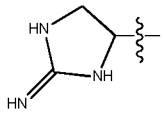
k. ,

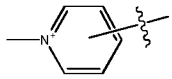
wherein M is selected from NR^{22}, $CR^{23}R^{24}$ and O,

wherein R^{22} is H and , wherein each of R^{15}, R^{16} and R^{17} is as described previously,

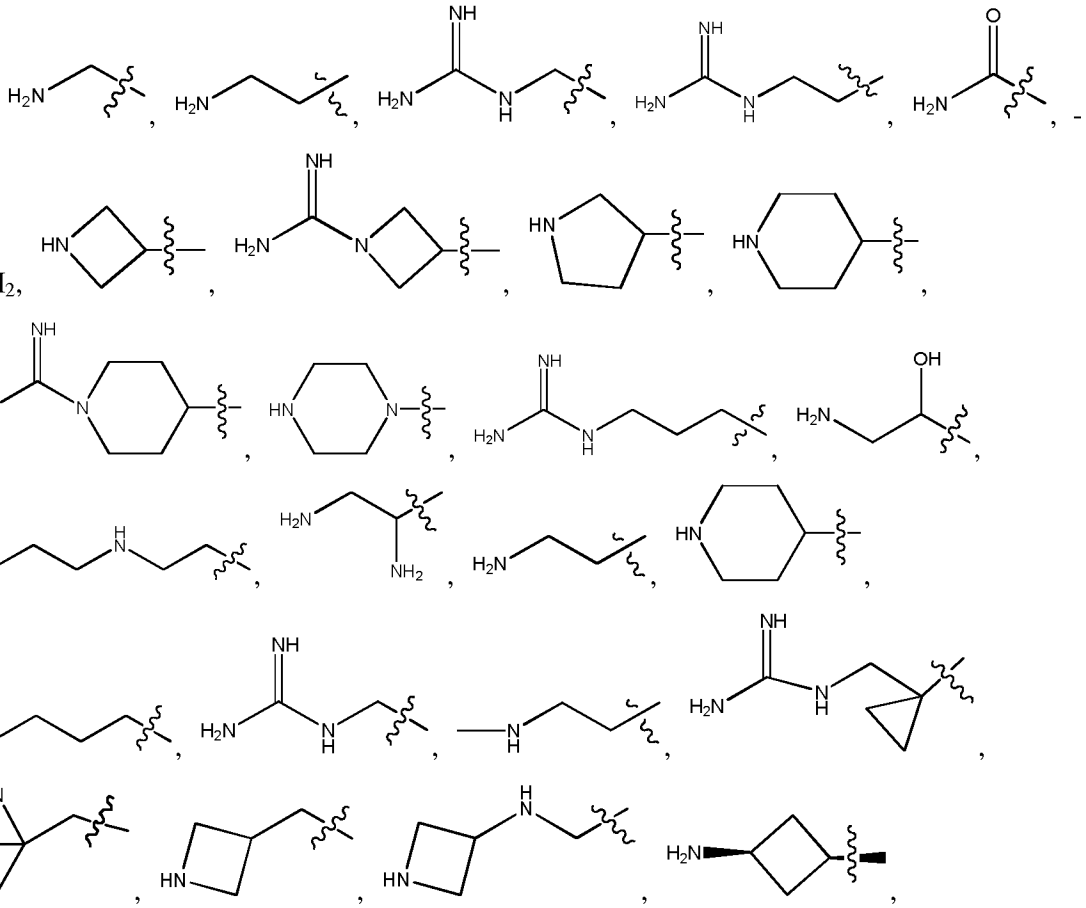
each of R^{23} and R^{24} is independently selected from H, NH_2 and 
wherein each of R^{4*}, R^{5*}, R^{6*} and R^{7*} is as described previously, and
u is selected from 0, 1 and 2;

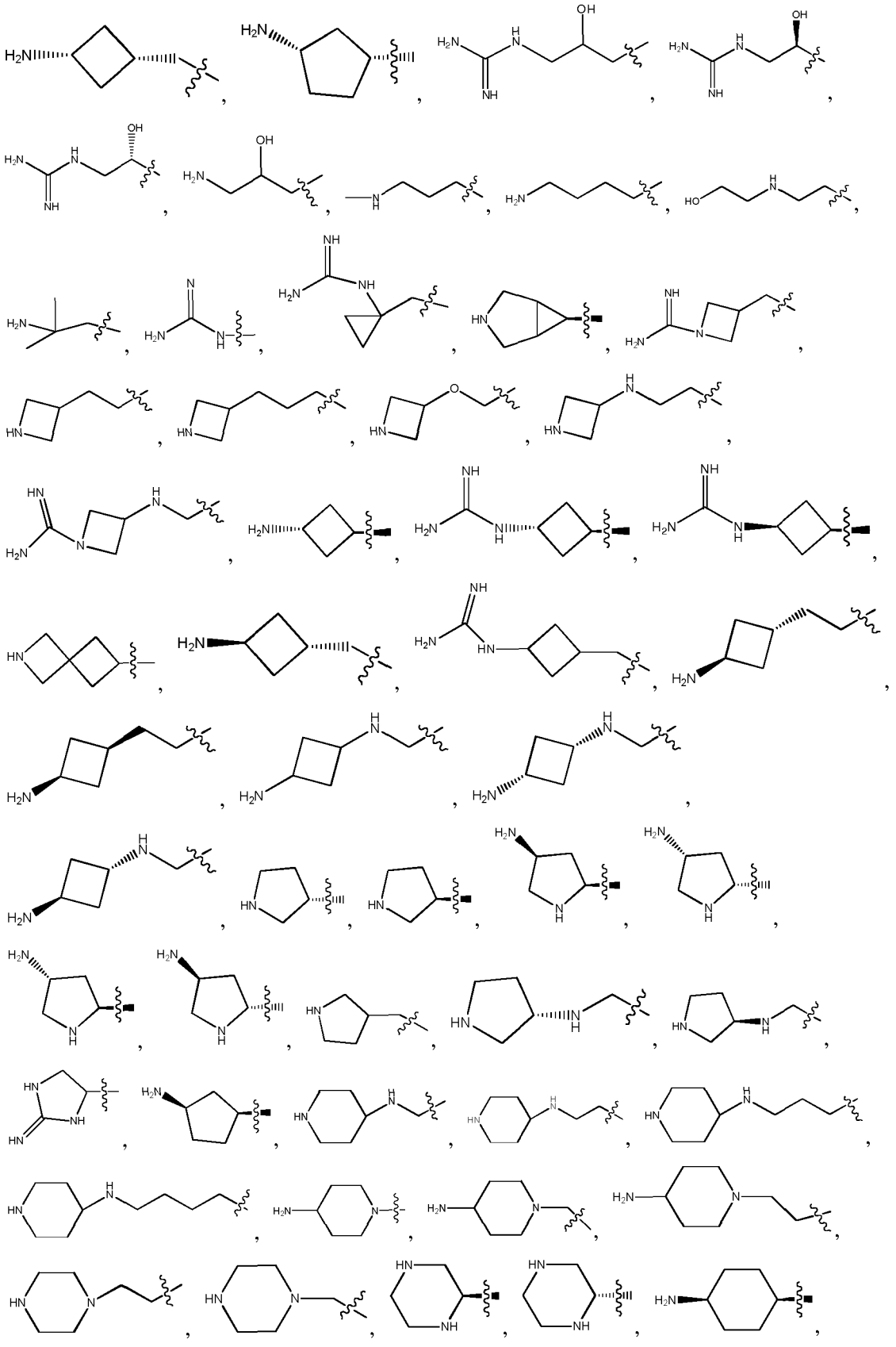
l. ;

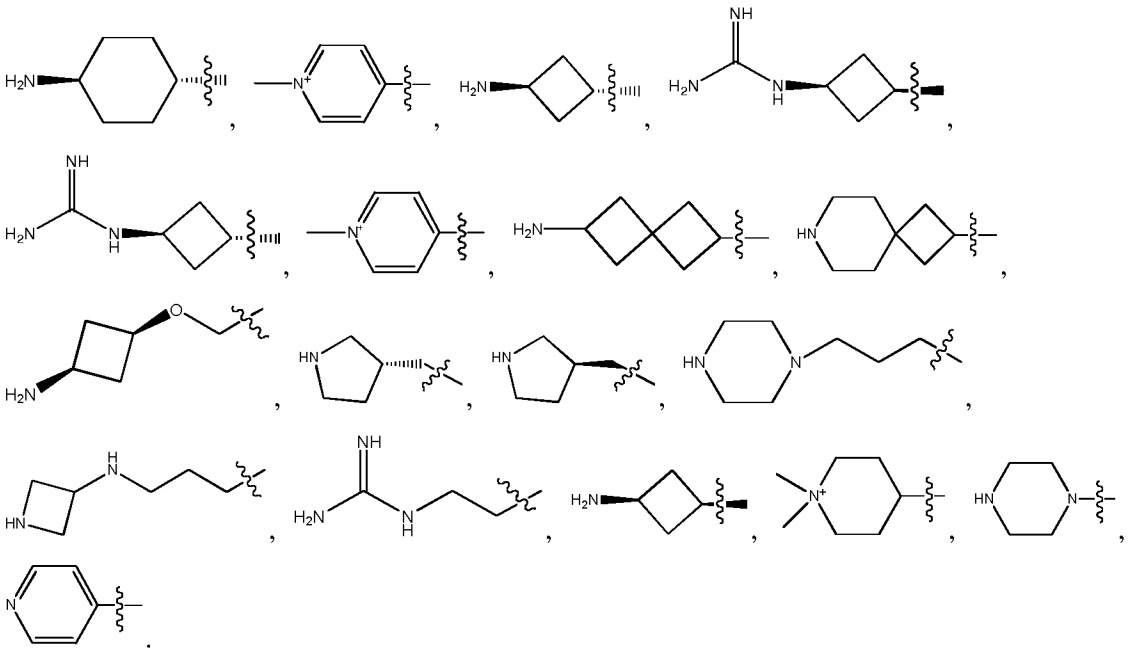
m. ; and

n. .

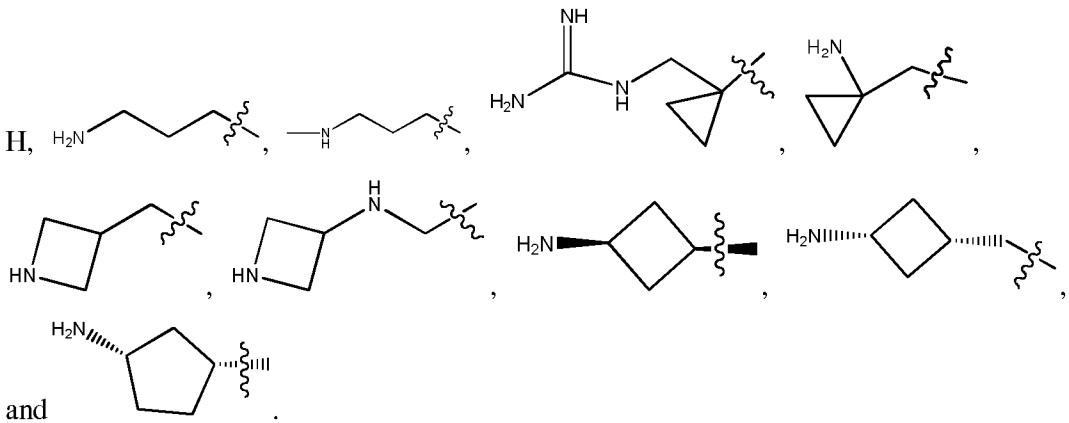
In one aspect of the invention R^{1*} is selected from

H, 

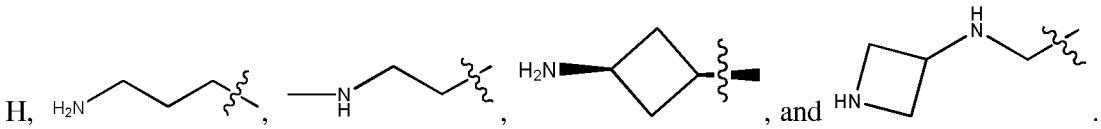




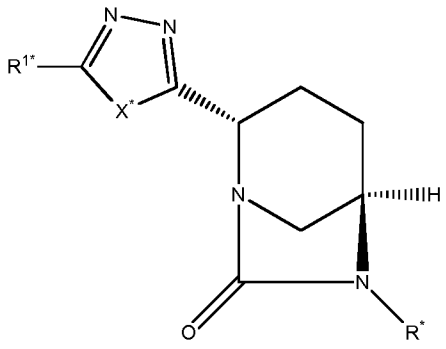
In one embodiment of the invention R^{1*} is selected from



In one embodiment of the invention R^{1*} is selected from



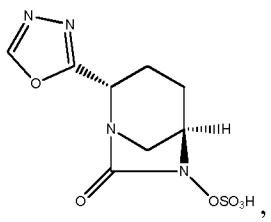
In one embodiment of the invention, the compounds of the invention are of the stereochemistry disclosed in Formula A-II.

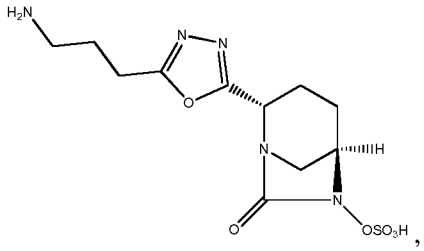


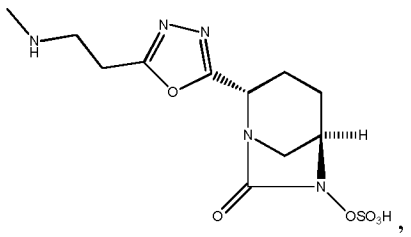
(A-II)

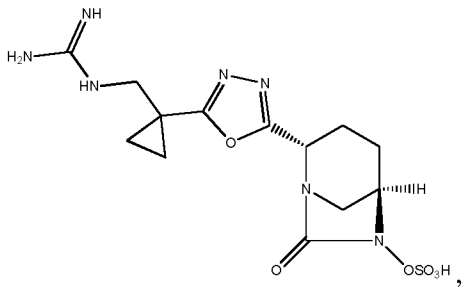
In another embodiment of the invention, X^*, R^* and R^{1*} are chosen from the substituents listed in Table I (See Figure I).

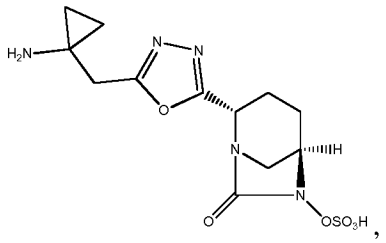
Preferred compounds of Formula A-I are

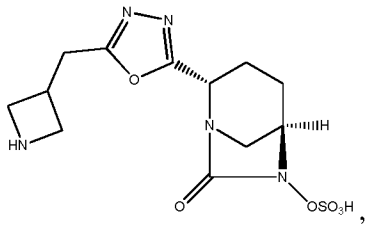


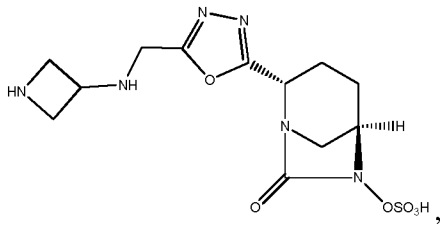
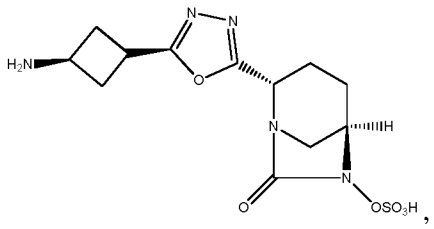
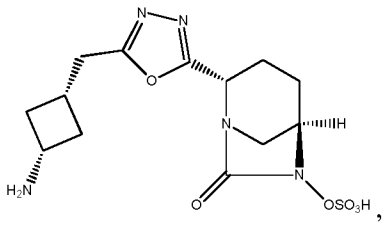
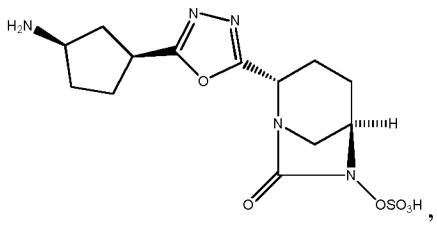










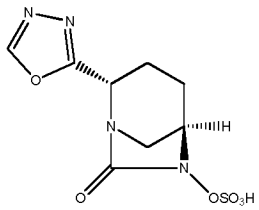





It will be understood by one of skill in the art that depending on the nature of R^{1*} and R^{*}, compounds of Formula I may exist in a salt or zwitterionic form.

Enzyme Inhibition and Binding Affinity

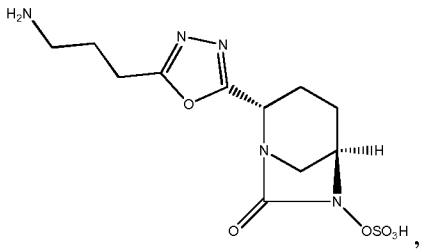
The compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) are effective in inhibiting β-lactamase. In one aspect of the invention the compounds of Table I are effective β-lactamase inhibitors.

In one aspect the compound



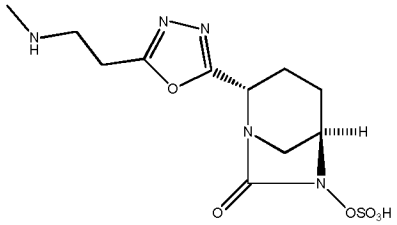
is effective in inhibiting β-lactamase.

In one aspect the compound



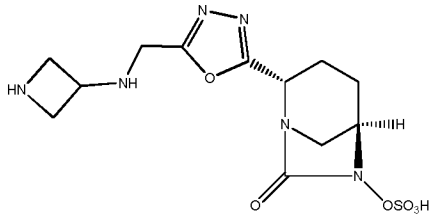
is effective in inhibiting β-lactamase.

In one aspect the compound



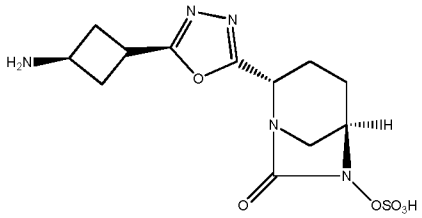
is effective in inhibiting β-lactamase.

In one aspect the compound



is effective in inhibiting β-lactamase.

In one aspect the compound

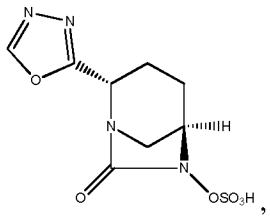


is effective in inhibiting β-lactamase.

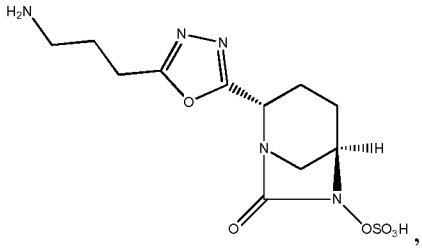
When used in combination with β-lactam antibiotics, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) potentiate the activity of the β-lactam antibiotic against microorganisms that are normally resistant to β-lactam antibiotics due to the presence of a β-lactamase or multiple β-lactamases.

In one aspect of the invention the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) inhibit β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of the invention the compounds of Formula I, inhibit β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of the invention the compounds of Formula A-I inhibit β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of the invention the compounds of Formula II inhibit β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of the invention the compounds of Formula A-II inhibit β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of

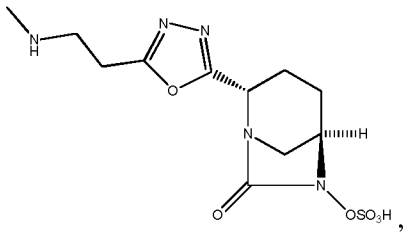
the invention the compounds of Table I inhibit β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of the invention the compound of the Formula



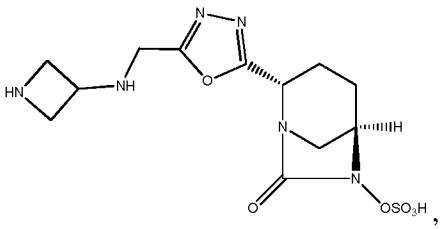
inhibits β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of the invention the compound of the Formula



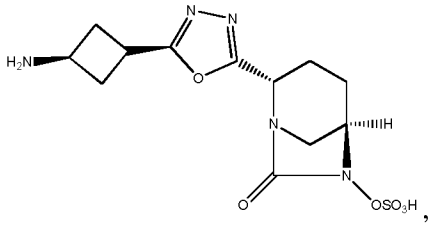
inhibits β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of the invention the compound of the Formula



inhibits β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of the invention the compound of the Formula



inhibits β-lactamases selected from class A, class C or class D β-lactamases. In one aspect of the invention the compound of the Formula



inhibits β-lactamases selected from class A, class C or class D β-lactamases. Class A β-

lactamases for example, include, but are not limited to, TEM, SHV, CTX-M, KPC, GES, VEB, SME, and GEX. In a preferred aspect of the invention, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) inhibit KPC β-lactamases. In a preferred aspect of the invention, the compounds of Formula I inhibit KPC β-lactamases. In a preferred aspect of the invention, the compounds of Formula A-I inhibit KPC β-lactamases. In a preferred aspect of the invention, the compounds of Formula II inhibit KPC β-lactamases. In a preferred aspect of the invention, the compounds of Formula A-II inhibit KPC β-lactamases. More preferably the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) inhibit KPC-2 or KPC-3 β-lactamases. More preferably the compounds of Formula I inhibit KPC-2 or KPC-3 β-lactamases. More preferably the compounds of Formula A-I inhibit KPC-2 or KPC-3 β-lactamases. More preferably the compounds of Formula II inhibit KPC-2 or KPC-3 β-lactamases. More preferably the compounds of Formula A- II inhibit KPC-2 or KPC-3 β-lactamases. In one aspect of the invention, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) inhibit KPC-2 or KPC-3 β-lactamases in clinical strains (Figure 2, Table II and Figures 6-9, Tables VI-IX). In one aspect of the invention, the compounds of Formula I inhibit KPC-2 or KPC-3 β-lactamases in clinical strains (Figure 2, Table II and Figures 6-9, Tables VI-IX). In one aspect of the invention, the compounds of Formula A-I inhibit KPC-2 or KPC-3 β-lactamases in clinical strains (Figure 2, Table II and Figures 6-9, Tables VI-IX). In one aspect of the invention, the compounds of Formula II inhibit KPC-2 or KPC-3 β-lactamases in clinical strains (Figure 2, Table II and Figures 6-9, Tables VI-IX). In one aspect of the invention, the compounds of Formula A-II inhibit KPC-2 or KPC-3 β-lactamases in clinical strains (Figure 2, Table II and Figures 6-9, Tables VI-IX). Class C β-lactamases for example, include, but are not limited to chromosomal AmpCs, and plasmid based ACC, DHA, CMY, FOX, ACT, MIR, LAT, MOX β-lactamases. Class D β-lactamase enzymes, for example, include, but are not limited to oxacillinases or OXA β-lactamases. In a preferred aspect of the invention, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) inhibit OXA-15 β-lactamases. In a preferred aspect of the invention, the compounds of Formula I inhibit OXA-15 β-lactamases. In a preferred aspect of the invention, the compounds of Formula A-I inhibit OXA-15 β-lactamases. In a preferred aspect of the invention, the compounds of

Formula II inhibit OXA-15 β-lactamases. In a preferred aspect of the invention, the compounds of Formula A-II inhibit OXA-15 β-lactamases.

Unless otherwise indicated, the activity of the BLI compounds can be described by the MIC value obtained from a Synergy MIC assay or a BLI potentiation assay (e.g as described herein), both of which are run in the presence of a β-lactam. The lower the sMIC or MIC value the more active the BLI, regardless of the mechanism of action of the BLI compound (e.g., including inhibition of β-lactamases by the BLI or any other mechanism of action or combination of mechanisms of action). The sMIC and BLI potentiation assay data supports that the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) potentiate (i.e. make more potent) the activity of the β-lactam antibiotic against β-lactamase producing strains by inhibiting the β-lactamase.

In one embodiment, the BLI activity is measured by growth inhibition of a β-lactamase producing bacterial strains in a Synergy MIC (sMIC) assay. Preferably, the sMIC value for the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is 8 μg/mL or less. In a more preferred aspect of the invention, the sMIC value for the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is 4 μg/mL to 8 μg/mL. In an even more preferred aspect of the invention, the sMIC value for the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is 1 to 2 μg/mL. In a still more preferred aspect of the invention, the sMIC value for the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is 0.2 to 0.5 μg/mL. Synergy MICs for representative compounds of the invention are described in Table III (See Figure 3). It will be understood by one of skill in the art that the growth inhibition of β-lactamase producing strains can also be measured by a checkerboard synergy assay like that disclosed in International Patent Application Number WO 2008/039420 or a standard BLI potentiation assay using a fixed concentration of BLI.

In one embodiment, the BLI activity is measured by growth inhibition of a β-lactamase producing bacterial strains in a standard BLI potentiation assay using a fixed concentration of BLI. Preferably, the MIC value for the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is 8 μg/mL or less. In a more preferred aspect of the invention, the MIC

value for the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is 4 to 8 μg/mL. In an even more preferred aspect of the invention, the MIC value for the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is 1 to 2 μg/mL. In a still more preferred aspect of the invention, the MIC value for the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is 0.2 μg/mL to 0.5 μg/mL.

The compounds of the present invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) have a broad spectrum of activity across a wide variety of β-lactamase producing bacteria. It was surprisingly found that the compounds of the present invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) are active in potentiating activity of β-lactam antibiotics, in particular, Ceftolozane, against strains expressing class D β-lactamase OXA-15 β-lactamase. Currently marketed BLIs inhibit most of the class A β-lactamases, but poorly inhibit class A KPC β-lactamases and class C β-lactamases and have variable success in inhibiting penicillinase and carbapenemase-type class D β-lactamases. The compounds of the present invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) are active against a wide variety of bacterial strains that express class A and C β-lactamases and also, surprisingly are active against bacterial strains that express the class D cephalosporinase OXA-15 (Tables II and III). This increased activity against the class D β-lactamase is critical because differential effectiveness against different types of β-lactamase producing bacteria is necessary in order to effectively use β-lactam antibiotics to treat resistant strains of bacteria (*vide infra*).

In one embodiment, the compounds the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) are unexpectedly more active against bacterial strains that express OXA-15 β-lactamases than the most structurally similar compound, Avibactam (comparator compound CCC). Compounds that are more active than Avibactam against bacterial strains that express the class D cephalosporinase OXA-15 are, for example, compounds 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744,

745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 776, 777, 778, 779, 780, 781, 782, 783, 784, 792, 794, 795 and 797.

In one embodiment, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) are unexpectedly more active against and/or show broader spectrum of activity against bacterial strains that express KPC β-lactamases than the most structurally similar compound, Avibactam. Compounds that are more active than Avibactam for at least one, bacterial strain that expresses KPC β-lactamase and/or show a better spectrum of activity against bacterial strains that express KPC β-lactamases than Avibactam are, for example, compounds 701, 702, 703, 705, 706, 708, 709, 710, 711, 712714, 720, 721, 722, 723, 724, 726, 727, 728, 729, 730, 731, 732, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 749, 750, 751, 752, 753, 754, 755, 756, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 770, 771, 772, 774, 775, 776, 777, 779, 782, 783, 784, 786, 794, and 795.

In another aspect of the invention, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) have high binding affinity for the β-lactamase enzyme. Consequently these compounds are better inhibitors of the β-lactamase enzyme. The inhibition kinetics of the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) was measured according to the procedure outlined in Example 102. The compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) have a high binding affinity for the β-lactamase enzyme.

In one embodiment the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) have a binding affinity of 1000-5000 $mM^{-1}s^{-1}$.

In one embodiment the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) have a binding affinity of 100-999 $mM^{-1}s^{-1}$. Compounds that have a binding affinity of 100-999 $mM^{-1}s^{-1}$ are, for example, compounds 701, 702, 703, 705, 706, 707, 709, 711, 712, 713, 714, 720, 730, 740, 741, 742, 743, 745, 746, 748, 749, 752, 753, 767, 770, 775, 779, 781, 782, 785, 794, 798 (Table IV).

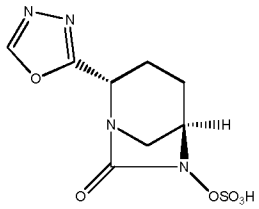
In one embodiment the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) have a binding affinity of 1-99 $mM^{-1}s^{-1}$. Compounds that have a binding affinity of 1-99 $mM^{-1}s^{-1}$ are, for example, compounds 704, 706, 708, 710, 715, 716, 717, 718, 719, 721, 722, 723, 724, 725, 726, 727, 728, 729, 731, 732, 733, 734, 735, 736, 737, 738, 739, 744, 747, 750, 751, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 769, 771, 772, 773, 774, 776, 777, 778, 780, 783, 784, 786, 792, 796, and 797 (Table IV).

It was surprisingly found that the compounds of the present invention have a higher binding affinity for the β-lactamase enzyme than the closest structural comparator Avibactam (Table IV, See Figure 4).

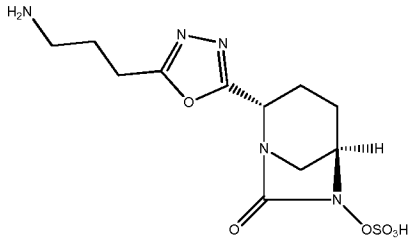
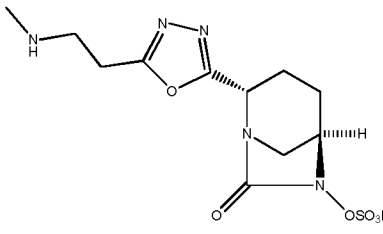
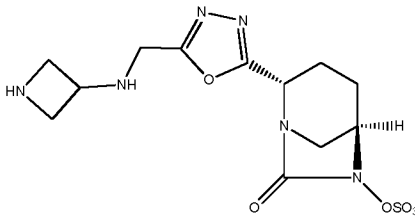
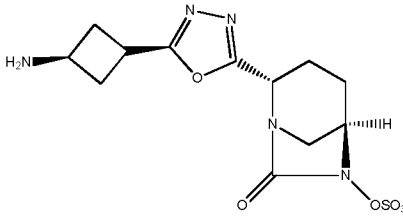
The compounds of the invention were also shown to be better BLIs than other comparator compounds as shown in Figure 5.

Pharmaceutical Compositions Comprising the Compounds of The Invention and Use Thereof

Another object of the invention is pharmaceutical compositions or formulations comprising compounds the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), or salts thereof, preferably further comprising a β-lactam antibiotic. In one embodiment of the invention is pharmaceutical compositions or formulations comprising compounds of Formula I, or salts thereof, preferably further comprising a β-lactam antibiotic. In one embodiment of the invention is pharmaceutical compositions or formulations comprising compounds of Formula A-I, or salts thereof, preferably further comprising a β-lactam antibiotic. In one embodiment of the invention is pharmaceutical compositions or formulations comprising compounds of Formula II, or salts thereof, preferably further comprising a β-lactam antibiotic. In one embodiment ofthe invention is pharmaceutical compositions or formulations comprising compounds of Formula A-II, or salts thereof, preferably further comprising a β-lactam antibiotic. In one embodiment of the invention is pharmaceutical compositions or formulations comprising compounds of Table I. In one embodiment of the invention is pharmaceutical compositions or formulations comprising compounds of Formula



, or salts thereof, preferably further comprising a β-lactam antibiotic. In

one embodiment of the invention is pharmaceutical compositions or formulations comprising compounds of Formula , or salts thereof, preferably further comprising a β-lactam antibiotic. In one embodiment the invention is pharmaceutical compositions or formulations comprising compounds of Formula , or salts thereof, preferably further comprising a β-lactam antibiotic. In one embodiment of the invention is pharmaceutical compositions or formulations comprising compounds of Formula , or salts thereof, preferably further comprising a β-lactam antibiotic. In one embodiment of the invention is pharmaceutical compositions or formulations comprising compounds of Formula , or salts thereof, preferably further comprising a β-lactam antibiotic.

The pharmaceutical compositions can be formulated for oral, intravenous, intramuscular, subcutaneous or parenteral administration for the therapeutic or prophylactic treatment of diseases, such as bacterial infections. Preferably, the pharmaceutical composition is formulated for intravenous administration.

The pharmaceutical preparations disclosed herein may be prepared in accordance with standard procedures and are administered at dosages that are selected to reduce, prevent or eliminate infection (see, e.g., Remington's Pharmaceutical Sciences, Mack Publishing

Company, Easton, PA and Goodman and Gilman's "The Pharmaceutical Basis of Therapeutics," Pergamon Press, New York, NY, the contents of which are incorporated herein by reference, for a general description of the methods for administering various antimicrobial agents for human therapy).

The pharmaceutical compositions can comprise one or more of the compounds disclosed herein (e.g. one or more compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II, in conjunction with a β-lactam antibiotic, in association with one or more nontoxic, pharmaceutically-acceptable carriers and/or diluents and/or adjuvants and/or excipients. As used herein, the phrase "pharmaceutically-acceptable carrier" refers to any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like, that are compatible with pharmaceutical administration. The use of such media and agents for pharmaceutically active substances is well known in the art. Non-limiting examples of carriers and excipients include corn starch or gelatin, lactose, sucrose, microcrystalline cellulose, kaolin, mannitol, dicalcium phosphate, sodium chloride and alginic acid. The compositions may contain croscarmellose sodium, microcrystalline cellulose, corn starch, sodium starch glycolate and alginic acid.

Tablet binders that can be included are acacia, methylcellulose, sodium carboxymethylcellulose, polyvinylpyrrolidone (Povidone), hydroxypropyl methylcellulose, sucrose, starch and ethylcellulose.

Lubricants that can be used include magnesium stearate or other metallic stearates, stearic acid, silicone fluid, talc, waxes, oils and colloidal silica.

Flavoring agents such as peppermint, oil of wintergreen, cherry flavoring or the like can also be used. It may also be desirable to add a coloring agent to make the dosage form more aesthetic in appearance or to help identify the product.

For oral or parenteral administration, compounds of the present invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) preferably a compound of Formula A-I or Formula A-II, in conjunction with a β-lactam antibiotic, can be mixed with conventional pharmaceutical carriers and excipients and used in the form of tablets, capsules, elixirs, suspensions, syrups, wafers and the like. The compositions comprising a compound of this invention may contain from about 0.1% to about 99% by weight of the active compound, such as from about 10% to about 30%.

For oral use, solid formulations such as tablets and capsules are useful. Sustained release or enterically coated preparations may also be devised. For pediatric and geriatric applications, one embodiment provides suspensions, syrups and chewable tablets. For oral administration, the pharmaceutical compositions are in the form of, for example, a tablet, capsule, suspension or liquid.

The pharmaceutical compositions may be made in the form of a dosage unit containing a therapeutically-effective amount of the active ingredient. Examples of such dosage units are tablets and capsules. For therapeutic purposes, the tablets and capsules which can contain, in addition to the active ingredient, conventional carriers such as binding agents, for example, acacia gum, gelatin, polyvinylpyrrolidone, sorbitol, or tragacanth; fillers, for example, calcium phosphate, glycine, lactose, maize-starch, sorbitol, or sucrose; lubricants, for example, magnesium stearate, polyethylene glycol, silica, or talc; disintegrants, for example, potato starch, flavoring or coloring agents, or acceptable wetting agents. Oral liquid preparations generally are in the form of aqueous or oily solutions, suspensions, emulsions, syrups or elixirs, preparations of the invention may contain conventional additives such as suspending agents, emulsifying agents, non-aqueous agents, preservatives, coloring agents and flavoring agents. Non-limiting examples of additives for liquid preparations include acacia, almond oil, ethyl alcohol, fractionated coconut oil, gelatin, glucose syrup, glycerin, hydrogenated edible fats, lecithin, methyl cellulose, methyl or propyl *para*-hydroxybenzoate, propylene glycol, sorbitol, or sorbic acid.

For intravenous (IV) use, the pharmaceutical composition (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) preferably a compound of Formula A-I or Formula A-II, in conjunction with a β-lactam antibiotic, can be dissolved or suspended in any of the commonly used intravenous fluids and administered by infusion. Intravenous fluids include, without limitation, physiological saline or Ringer's solution. Intravenous administration may be accomplished by using, without limitation, syringe, mini-pump or intravenous line.

Pharmaceutical compositions of this invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) preferably a compound of Formula A-I or Formula A-II, for parenteral injection comprise pharmaceutically-acceptable aqueous or non-aqueous solutions, dispersions, suspensions or emulsions as well as sterile powders for reconstitution into sterile injectable solutions or dispersions just prior to use. Examples of suitable aqueous and non-aqueous carriers,

diluents, solvents or vehicles include water, ethanol, benzyl alcohol, polyols (such as glycerol, propylene glycol, and polyethylene glycol), and suitable mixtures thereof, vegetable oils (such as corn oil or olive oil), and injectable organic esters such as ethyl oleate. Proper fluidity can be maintained, for example, by the use of coating materials such as lecithin, by the maintenance of the required particle size in the case of dispersions, and by the use of surfactants. The compositions can include various buffers.

These compositions may also contain adjuvants such as preservatives, wetting agents, emulsifying agents, and dispersing agents. They may also contain taggants or other anti-counterfeiting agents, which are well known in the art. Prevention of the action of microorganisms may be ensured by the inclusion of various antibacterial and antifungal agents, for example, paraben, chlorobutanol, and phenol sorbic acid. It may also be desirable to include isotonic agents such as sugars and sodium chloride. Prolonged absorption of the injectable pharmaceutical form may be brought about by the inclusion of agents which delay absorption, such as aluminum monostearate and gelatin.

Injectable depot forms can be made by forming microencapsulating matrices of the drug in biodegradable polymers such as polylactide-polyglycolide. Depending upon the ratio of drug to polymer and the nature of the particular polymer employed, the rate of drug release can be controlled. Examples of other biodegradable polymers include poly(orthoesters) and poly(anhydrides). Depot injectable formulations can also be prepared by entrapping the drug in liposomes or microemulsions, which are compatible with body tissues.

The injectable formulations can be sterilized, for example, by filtration through a bacterial-retaining filter, or by incorporating sterilizing agents in the form of sterile solid compositions, which can be dissolved or dispersed in sterile water or other sterile injectable medium just prior to use.

Solid dosage forms for oral administration include capsules, tablets, pills, powders, and granules. Such forms may include forms that dissolve or disintegrate quickly in the oral environment. In such solid dosage forms, the active compound preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, can be mixed with at least one inert, pharmaceutically-acceptable excipient or carrier. Suitable excipients include, for example, (a) fillers or extenders such as starches, lactose, sucrose, glucose, mannitol, and silicic acid; (b) binders such as cellulose and cellulose derivatives (such as hydroxypropylmethylcellulose, hydroxypropylcellulose, and carboxymethylcellulose), alginates, gelatin, polyvinylpyrrolidone, sucrose, and acacia; (c) humectants such as glycerol;

(d) disintegrating agents such as sodium starch glycolate, croscarmellose, agar-agar, calcium carbonate, potato or tapioca starch, alginic acid, certain silicates, and sodium carbonate; (e) solution retarding agents such as paraffin; (f) absorption accelerators such as quaternary ammonium compounds; (g) wetting agents, such as cetyl alcohol and glycerol monostearate, fatty acid esters of sorbitan, poloxamers, and polyethylene glycols; (h) absorbents such as kaolin and bentonite clay; (i) lubricants such as talc, calcium stearate, magnesium stearate, solid polyethylene glycols, sodium lauryl sulfate, and mixtures thereof; and (j) glidants such as talc, and silicone dioxide. Other suitable excipients include, for example, sodium citrate or dicalcium phosphate. The dosage forms may also comprise buffering agents.

Solid dosage forms, including those of tablets, dragees, capsules, pills, and granules, can be prepared with coatings and shells such as functional and aesthetic enteric coatings and other coatings well known in the pharmaceutical formulating art. They may optionally contain opacifying agents and colorants. They may also be in a form capable of controlled or sustained release. Examples of embedding compositions that can be used for such purposes include polymeric substances and waxes.

The pharmaceutical compositions can be delivered using controlled (e.g., capsules) or sustained release (e.g., bioerodable matrices) delivery systems. Exemplary delayed release delivery systems for drug delivery that are suitable for administering the pharmaceutical compositions are described in U.S. Patent Nos. 4,452,775 (issued to Kent), 5,039,660 (issued to Leonard), and 3,854,480 (issued to Zaffaroni).

In some cases, in order to prolong the effect of the drug, it may be desirable to slow the absorption of the drug following subcutaneous or intramuscular injection. This may be accomplished by the use of a liquid suspension of crystalline or amorphous material with poor water solubility. Amorphous material may be used alone or together with stabilizers as necessary. The rate of absorption of the drug then depends upon its rate of dissolution, which in turn, may depend upon crystal size and crystalline form.

Alternatively, delayed absorption of a parenterally administered drug form can be accomplished by dissolving or suspending the drug in an oil vehicle.

For intramuscular preparations, a sterile formulation of compounds, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, or suitable soluble salt forms thereof, for example hydrochloride salts, can be dissolved and administered in a pharmaceutical diluent such as Water-for-Injection (WFI), physiological saline or 5% glucose. A suitable insoluble form of the compound may be prepared and

administered as a suspension in an aqueous base or a pharmaceutically acceptable oil base, e.g., an ester of a long chain fatty acid such as ethyl oleate.

A dose of an intravenous, intramuscular, or parental formulation of compounds, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, may be administered as a bolus or by slow infusion. A bolus is a dose that is administered in less than 30 minutes. In one embodiment, a bolus is administered in less than 15 or less than 10 minutes. In another embodiment, a bolus is administered in less than 5 minutes. In yet another embodiment, a bolus is administered in one minute or less. An infusion is a dose that is administered at a rate of 30 minutes or greater. In one embodiment, the infusion is one hour or greater. In another embodiment, the infusion is substantially constant.

For topical use the pharmaceutical compositions, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, can also be prepared in suitable forms to be applied to the skin, or mucus membranes of the nose and throat, and can take the form of creams, ointments, liquid sprays or inhalants, lozenges, or throat paints. Such topical formulations further can include chemical compounds such as dimethylsulfoxide (DMSO) to facilitate surface penetration of the active ingredient.

For application to the eyes or ears, the pharmaceutical composition can be presented in liquid or semi-liquid form formulated in hydrophobic or hydrophilic bases as ointments, creams, lotions, paints or powders.

For rectal administration, the pharmaceutical compositions, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, can be administered in the form of suppositories admixed with conventional carriers such as cocoa butter, polyethylene glycol or a suppository wax or other glyceride that are solid at room temperature but liquid at body temperature and therefore melt in the rectum or vaginal cavity and release the active compound.

Alternatively, the pharmaceutical compositions can be in powder form for reconstitution in the appropriate pharmaceutically acceptable carrier at the time of delivery. In another embodiment, the unit dosage form of compounds, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, can be a solution of one or more compounds, or salts thereof, in a suitable diluent, in sterile hermetically sealed ampoules or sterile syringes. The concentration of the compounds, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, in the unit dosage

may vary, e.g. from about 1 percent to about 50 percent, depending on the compound used and its solubility and the dose desired by the physician. If the compositions contain dosage units, each dosage unit can contain from 1-500 mg of the active material. For adult human treatment, the dosage employed can range from 5 mg to 10 g, per day, depending on the route and frequency of administration.

The pharmaceutical compositions disclosed herein can be placed in a pharmaceutically acceptable carrier and are delivered to a recipient subject (e.g., a human) in accordance with known methods of drug delivery. In general, the methods of delivering the pharmaceutical compositions *in vivo* utilize art-recognized protocols for delivering the agent with the only substantial procedural modification being the substitution of the compounds of the present invention for the drugs in the art-recognized protocols. Likewise, methods for using the claimed compositions for treating cells in culture, for example, to eliminate or reduce the level of bacterial contamination of a cell culture, utilize art-recognized protocols for treating cell cultures with antibacterial agent(s) with the only substantial procedural modification being the substitution of the compounds of the present invention, preferably in combination with a β-lactam antibiotic for the drugs in the art-recognized protocols.

Exemplary procedures for delivering an antibacterial agent are described in U.S. Patent Nos. 6,468,967; 6,852,689; and 5,041,567, issued to Rogers and in PCT patent application number EP94/02552 (publication no. WO 95/05384), the disclosures of which are incorporated herein by reference in their entirety. In one embodiment, one or more compounds of the invention, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, or pharmaceutical compositions thereof are administered orally, rectally or via injection (intravenous, intramuscular or subcutaneous). In another embodiment, one or more compounds of the invention, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, or pharmaceutical compositions thereof are administered orally, rectally or via injection (intravenous, intramuscular or subcutaneous) to treat an infection caused by β-lactam resistant bacteria. In another embodiment, one or more compounds of the invention, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, or pharmaceutical compositions thereof are administered orally to treat an infection caused by β-lactamase producing bacteria.

As used herein, the phrases "therapeutically-effective dose" and "therapeutically-effective amount" refer to an amount of a compound that prevents the onset, alleviates the

symptoms, stops the progression of a bacterial infection, or results in another desired biological outcome such as, e.g., improved clinical signs or reduced/elevated levels of lymphocytes and/or antibodies.

The term "treating" or "treatment" is defined as administering, to a subject, a therapeutically-effective amount of one or more compounds both to prevent the occurrence of an infection and to control or eliminate an infection. Those in need of treatment may include individuals already having a particular medical disease as well as those at risk for the disease (*i.e.*, those who are likely to ultimately acquire the disorder).

The term "subject," as used herein, refers to a mammal, a plant, a lower animal, or a cell culture. In one embodiment, a subject is a human or other animal patient in need of antibacterial treatment.

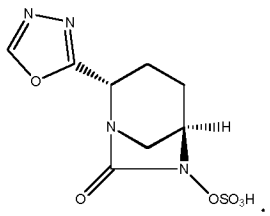
The term "administering "or "administration" and the like, refers to providing the compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) to the subject in need of treatment. Preferably the subject is a mammal, more preferably a human. The present invention comprises administering the compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) in conjunction with a β-lactam antiobiotic. When a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is administered in conjunction with a β-lactam antiobiotic, the compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) and the β-lactam antiobiotic can be administered at the same time or different times. When the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) and the β-lactam antiobiotic are administered at the same time, they can be administered as a single composition or pharmaceutical composition or they can be administered separately. It is understood that when a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is administered in conjunction with a β-lactam antibiotic, that the active agents can be administered in a single combination or in multiple combinations. For example, when administered by IV, the compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) can be dissolved or suspended in any of the commonly used intravenous fluids and administered by infusion, then a β-lactam antibiotic can be dissolved or suspended in any of the commonly

used intravenous fluids and administered by infusion. Conversely the β-lactam antibiotic can be dissolved or suspended in any of the commonly used intravenous fluids and administered by infusion, then a compound of Formula I can be dissolved or suspended in any of the commonly used intravenous fluids and administered by infusion. Alternatively, a pharmaceutical composition comprising a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) and a β-lactam antibiotic can be dissolved or suspended in any of the commonly used intravenous fluids and administered by infusion.

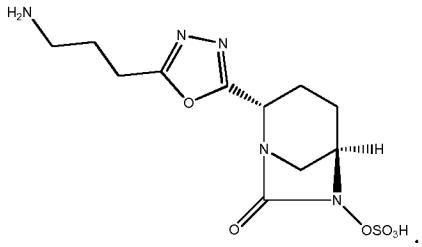
In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition comprising a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) and a β-lactam antibiotic. In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition comprising a compound of Formula I, and a β-lactam antibiotic. In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition comprising a compound of Formula A-I, and a β-lactam antibiotic. In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition comprising a compound of Formula II, and a β-lactam antibiotic. In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition comprising a compound of Formula A-II, and a β-lactam antibiotic.

In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II). In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Formula I. In one embodiment of the invention, is provided a method of

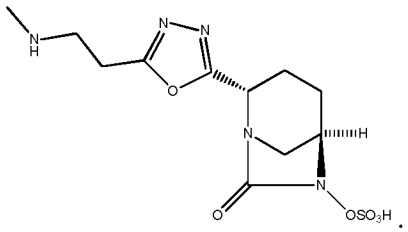
treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Formula A-I. In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Formula II. In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Formula A-II. In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Table I. In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Formula



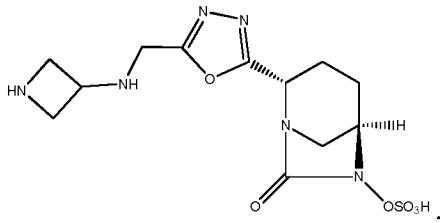
In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Formula



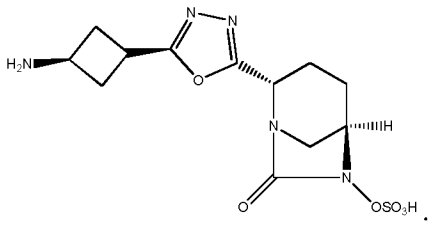
In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Formula



In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Formula



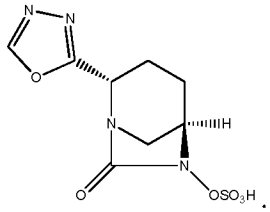
In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of Formula



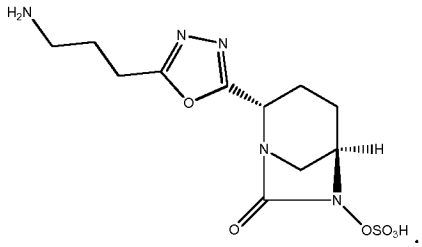
In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection in a subject comprising the steps of

a. administering to the subject a compound of the invention; and
b. administering to the subject a therapeutically-effective amount of a β-lactam antibiotic.

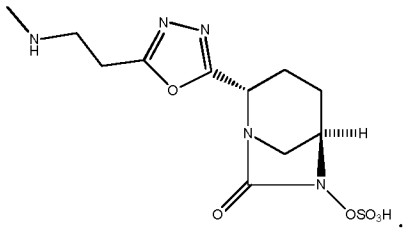
In one embodiment the compound in step a is a compound of Formula I. In one embodiment the compound in step a is a compound of Formula A-I. In one embodiment the compound in step a is a compound of Formula II. In one embodiment the compound in step a is a compound of Formula A-II. In one embodiment the compound in step a is a compound of Table I. In one embodiment the compound in step a is a compound of Formula A-II. In one

embodiment the compound in step a is a compound of Formula .

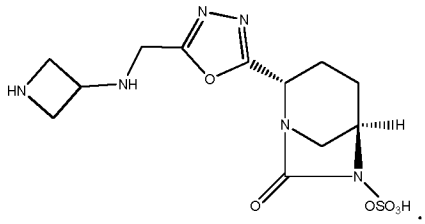
In one embodiment the compound in step a is a compound of Formula

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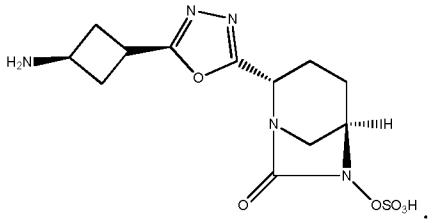
In one embodiment the compound in step a is a compound of Formula

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In one embodiment the compound in step a is a compound of Formula

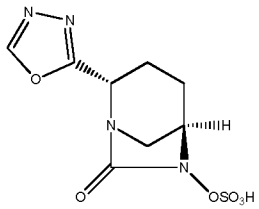
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In one embodiment the compound in step a is a compound of Formula

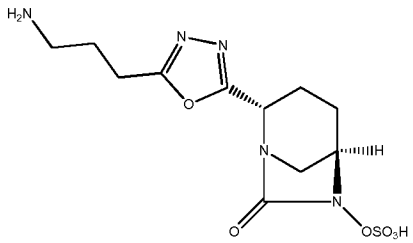
.

In one embodiment, the β-lactam antibiotic in step b is Ceftolozane, Ceftazidime, Aztreonam or Meropenem, or more preferably, Ceftolozane or Ceftazidime.

In one embodiment the compound in step a is a compound of Formula

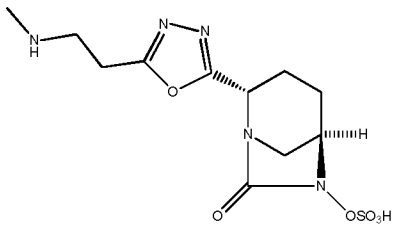


and the β-lactam antibiotic in step b is Ceftolozane. In one embodiment the compound in step a is a compound of Formula



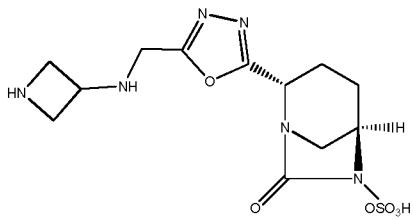
and the β-lactam antibiotic in step b is Ceftolozane.

In one embodiment the compound in step a is a compound of Formula



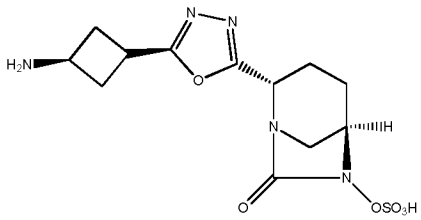
and the β-lactam antibiotic in step b is Ceftolozane.

In one embodiment the compound in step a is a compound of Formula



and the β-lactam antibiotic in step b is Ceftolozane.

In one embodiment the compound in step a is a compound of Formula

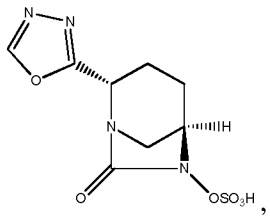


and the β-lactam antibiotic in step b is Ceftolozane.

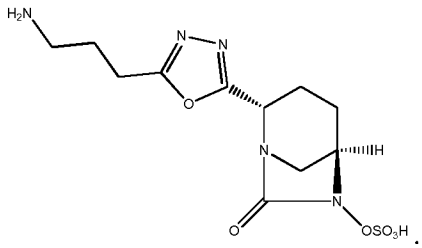
In one embodiment of the invention, is provided a method of treating or preventing a bacterial infection in a subject comprising the steps of

a. administering to the subject a therapeutically-effective amount of a β-lactam antibiotic; and

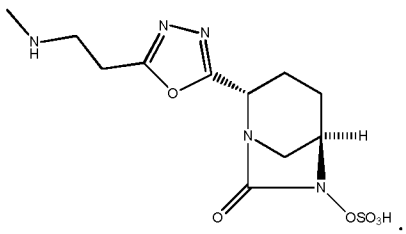
b. administering to the subject a compound of the invention .

In one embodiment the compound in step b is a compound of Formula I. In one embodiment the compound in step b is a compound of Formula A-I. In one embodiment the compound in step b is a compound of Formula II. In one embodiment the compound in step b is a compound of Formula II. In one embodiment the compound in step b is a compound of Table I. In one embodiment the compound in step b is a compound of Formula ,

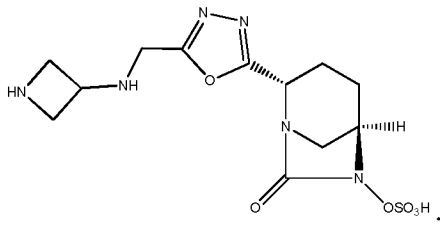
In one embodiment the compound in step b is a compound of Formula

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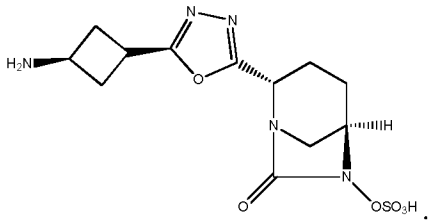
In one embodiment the compound in step b is a compound of Formula

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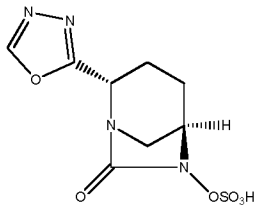
In one embodiment the compound in step b is a compound of Formula

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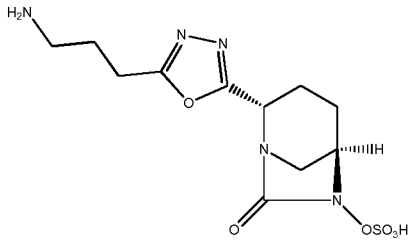
In one embodiment the compound in step b is a compound of Formula



In one embodiment, the β-lactam antibiotic in step a is Ceftolozane, Ceftazidime, Aztreonam or Meropenem, or more preferably, Ceftolozane or Ceftazidime. In one embodiment the compound in step b is a compound of Formula

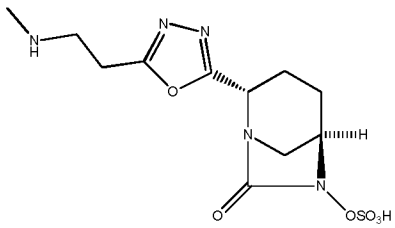


and the β-lactam antibiotic in step a is Ceftolozane. In one embodiment the compound in step b is a compound of Formula



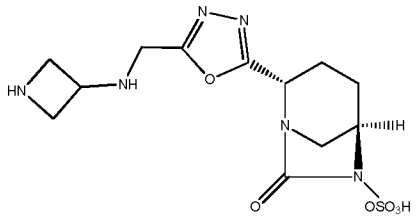
and the β-lactam antibiotic in step a is Ceftolozane.

In one embodiment the compound in step b is a compound of Formula



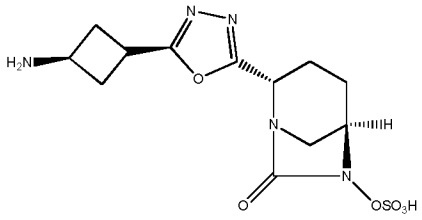
and the β-lactam antibiotic in step a is Ceftolozane.

In one embodiment the compound in step b is a compound of Formula



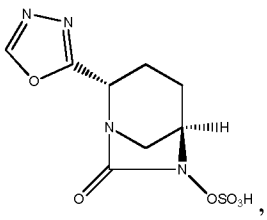
and the β-lactam antibiotic in step a is Ceftolozane.

In one embodiment the compound in step b is a compound of Formula

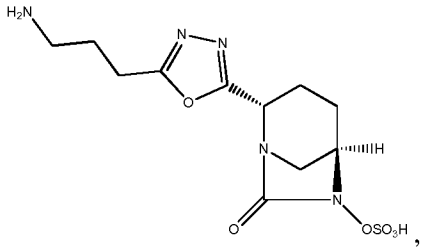


and the β-lactam antibiotic in step a is Ceftolozane.

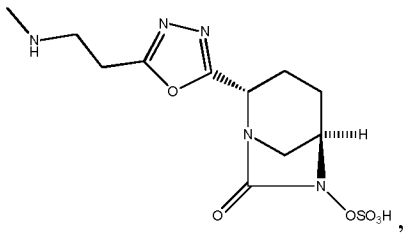
In one embodiment, the invention provides a method for treating an infection in a subject by administering a therapeutically-effective amount of one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β- lactam antibiotic, or compositions thereof. In one embodiment, the method comprises administering to a subject in need thereof a pharmaceutical composition comprising at least one of the compounds described herein, preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic. In one embodiment the compound is of Formula



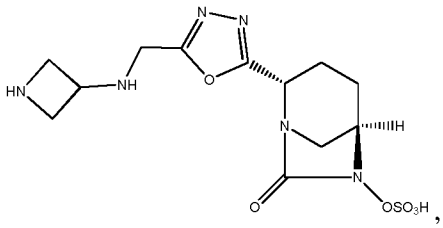
in conjunction with a β-lactam antibiotic, preferably Ceftolozane, Ceftazidime, Aztreonam or Meropenem, or more preferably, Ceftolozane or Ceftazidime, or compositions thereof. In one embodiment the compound is of Formula



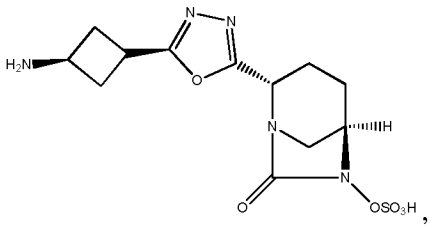
in conjunction with a β-lactam antibiotic, preferably Ceftolozane, Ceftazidime, Aztreonam or Meropenem, or more preferably, Ceftolozane or Ceftazidime, or compositions thereof. In one embodiment the compound is of Formula



in conjunction with a β-lactam antibiotic, preferably Ceftolozane, Ceftazidime, Aztreonam or Meropenem, or more preferably, Ceftolozane or Ceftazidime, or compositions thereof. In one embodiment the compound is of Formula



in conjunction with a β-lactam antibiotic, preferably Ceftolozane, Ceftazidime, Aztreonam or Meropenem, or more preferably, Ceftolozane or Ceftazidime, or compositions thereof. In one embodiment the compound is of Formula



in conjunction with a β-lactam antibiotic, preferably Ceftolozane, Ceftazidime, Aztreonam or Meropenem, or more preferably, Ceftolozane or Ceftazidime, or compositions thereof. In one embodiment, the pharmaceutical composition can comprise any one of the compounds described herein as the sole active compound or in combination with another compound, composition, or biological material. The compound may be administered orally, parenterally, by inhalation, topically, rectally, nasally, buccally, vaginally, or by an implanted reservoir, external pump or catheter. The compound may be prepared for opthalmic or aerosolized uses. The compounds of the present invention can be administered as an aerosol for the treatment of pneumonia or other lung-based infections. In one embodiment, the aerosol delivery vehicle is an anhydrous or dry powder inhaler. One or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in

conjunction with a β-lactam antibiotic, or pharmaceutical compositions thereof also may be directly injected or administered into an abscess, ventricle or joint. Parenteral administration includes subcutaneous, intravenous, intramuscular, intra-articular, intra-synovial, cisternal, intrathecal, intrahepatic, intralesional and intracranial injection or infusion. In one embodiment, one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, are administered intravenously, subcutaneously or orally. In one embodiment for administering one or more compounds according to the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic to a cell culture, the one or more compounds may be administered in a nutrient medium.

In one embodiment, one or more compounds according to the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or A-II in conjunction with a β-lactam antibiotic, may be used to treat a subject having a bacterial infection in which the infection is caused or exacerbated by any type of bacteria, such as Gram-negative bacteria. In one aspect of the invention, the bacterial infection is caused by β-lactam resistant bacteria. In one aspect the bacterial infection is caused by β-lactamase producing bacteria. In another aspect the bacterial infection is caused by class A, class C or class D β-lactamase producing bacteria. In another aspect the bacterial infection is caused by class A β-lactamase producing bacteria. In another aspect the infection is caused by class C β-lactamase producing bacteria. In still another aspect the infection is caused by class D β-lactamase producing bacteria. In still another aspect the infection is caused by KPC β-lactamase producing bacteria. In still another aspect the infection is caused by OXA β-lactamase producing bacteria. In still another aspect, the bacterial infection is caused by a bacteria that produces multiple β-lactamases. Bacteria that produce multiple β-lactamases may produce β-lactamases of the same class or of different classes (e.g class A and class A or class A and class C or class A and class D etc).

Representative Gram-negative pathogens known to express β-lactamases include, but are not limited to *Acinetobacter* spp. (including *Acinetobacter baumannii*), *Citrobacter* spp., *Escherichia* spp. (including *Escherichia coli*), *Haemophilus influenzae*, *Morganella*

morganii, *Pseudomonas aeruginosa*, *Klebsiella* spp. (including *Klebsiella pneumoniae*), *Enterobacter* spp. (including *Enterobacter cloacae and Enterobacter aerogenes*), *Pasteurella* spp., *Proteus* spp. (including *Proteus mirabilis*), *Serratia* spp. (including *Serratia marcescens*), and *Providencia* spp. Bacterial infections can be caused or exacerbated by Gram-negative bacteria including strains which express β-lactamases that may confer resistance to penicillins, cephalosporins, monobactams and/or carbapenems. The co-administration of a novel BLI that inhibits these β-lactamases with a β-lactam antibiotic could be used to treat infections caused by β-lactam resistant bacteria.

In one aspect of the invention the infection is caused by a β-lactamase producing bacteria selected from *Acinetobacter* spp, *Citrobacter* spp, *Escherichia coli, Enterobacter cloacae*), *Haemophilus influenzae*, *Pseudomonas aeruginosa*, *Proteus mirabilis, Serratia marcescens,* and *Klebsiella pneumoniae*,

β-Lactam antibiotics that may be administered concurrently with compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) include, but are not limited to cephalosporin, carbapenem, monobactam, penem and penicillin classes of antibiotics.

In one embodiment of the invention, the β-lactam antibiotic is a cephalosporin. Examples of cephalosporins include, but are not limited to, Cefacetrile (cephacetrile), Cefadroxil (cefadroxyl), Cefalexin (cephalexin), Cefaloglycin (cephaloglycin), Cefalonium (cephalonium), Cefaloridine (cephaloradine), Cefalotin (cephalothin), Cefapirin (cephapirin), Cefatrizine,Cefazaflur, Cefazedone, Cefazolin (cephazolin), Cefradine (cephradine), Cefroxadine, Ceftezole, Cefaclor, Cefamandole, Cefmetazole, Cefonicid, Cefotetan, Cefoxitin, Cefprozil (cefproxil), Cefuroxime, Cefuzonam, Cefcapene, Cefdaloxime, Cefdinir, Cefditoren, Cefetamet, Cefixime, Cefmenoxime, Cefodizime, Cefotaxime, Cefpimizole, Cefpodoxime, Cefteram, Ceftibuten, Ceftiofur, Ceftiolene, Ceftizoxime, Ceftriaxone, Cefoperazone, Ceftazidime, Cefclidine, Cefepime, Cefluprenam, Cefoselis, Cefozopran, Cefpirome, Cefquinome, Cefaclomezine, Cefaloram, Cefaparole, Cefcanel, Cefedrolor, Cefempidone, Cefetrizole, Cefivitril, Cefmatilen, Cefmepidium, Cefovecin, Cefoxazole, Cefrotil, Cefsumide, Ceftaroline, Ceftioxide, Cefuracetime, cefbuperazone, cefminox, ceforanide, cefotiam, cefpiramide, cefsulodin, ceftobiprole latamoxef, loracarbef and Ceftolozane. In one embodiment the cephalosporin is Ceftolozane or Ceftazidime.

In one embodiment of the invention, the β-lactam antibiotic is a carbapenen. Examples of carbapenem antibiotics include, but are not limited to, Imipenem,

Imipenem/Cilastatin, Biapenem, Doripenem, Meropenem, Ertapenem and Panipenem. In one embodiment the Carbapenem is Imipenem/Cilastatin or Meropenem.

In one embodiment of the invention, the β-lactam antibiotic is a monobactam. Examples of monobactam antibiotics include, but are not limited to Aztreonam, Tigemonam, Carumonam, BAL30072 and Nocardicin A.

In one embodiment of the invention, the β-lactam antibiotic is a penem. In one embodiment of the invention, the β-lactam antibiotic is a penicillin. Examples of penicillin antibiotics include, but are not limited to Amoxicillin, Ampicillin, Azlocillin, Mezlocillin, Apalcillin, Hetacillin, Becampicillin, Carbenicillin, Sulbenicillin, Ticarcillin, Piperacillin, Azlocillin, Mecillinam, Pivmecillinam, Methicillin, Ciclacillin, Talampicillin, Aspoxicillin, Oxacillin, Cloxacillin, Dicloxacillin, Flucloxacillin, Nafcillin and Pivampicillin.

In one embodiment the cephalosporin is Ceftolozane, Ceftazidime, Aztreonam or Meropenem, or more preferably, Ceftolozane or Ceftazidime.

The pharmaceutical compositions, preferably a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) in conjunction with a β-lactam antibiotic, can be used to treat a bacterial infection of any organ or tissue in the body caused by β-lactam resistant bacteria, preferably, Gram-negative β-lactam resistant bacteria. These organs or tissue include, without limitation, skeletal muscle, skin, bloodstream, kidneys, heart, lung and bone. For example, a pharmaceutical composition comprising at least one compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, can be administered to a subject to treat, without limitation, skin and soft tissue infections (e.g., complex skin infections), bacteremia, intra-abdominal infections and urinary tract infections (e.g., cUTI). In addition, a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) may be used to treat community acquired respiratory infections, including, without limitation, otitis media, sinusitis, chronic bronchitis and pneumonia (including community-acquired pneumonia, hospital-acquired pneumonia and ventilator associated pneumonia), including pneumonia caused by drug-resistant *Pseudomonas aeruginosa* . At least one compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam

antibiotic, can be administered to a subject to treat mixed infections that comprise different types of Gram-negative bacteria, or which comprise both Gram-positive and Gram-negative bacteria. These types of infections include intra-abdominal infections and obstetrical/gynecological infections. At least one compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, may also be administered to a subject to treat an infection including, without limitation, endocarditis, nephritis, septic arthritis, intra-abdominal sepsis, bone and joint infections and osteomyelitis. At least one compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, or pharmaceutical compositions thereof, may also be directly injected or administered into an abscess, ventricle or joint. Pharmaceutical compositions of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, may be administered as an aerosol for the treatment of pneumonia or other lung-based infections. In one embodiment, the aerosol delivery vehicle is an anhydrous, liquid or dry powder inhaler.

Actual dosage levels of active ingredients in the pharmaceutical compositions of one or more compounds according to the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, may be varied so as to obtain a therapeutically-effective amount of the active compound(s) to achieve the desired therapeutic response for a particular patient, compositions, and mode of administration. The effective amount can be determined as described herein. The selected dosage level will depend upon the activity of the particular compound, the route of administration, the severity of the condition being treated, and the condition and prior medical history of the patient being treated. However, it is within the skill of the art to start doses of the compound at levels lower than required to achieve the desired therapeutic effect and to gradually increase the dosage until the desired effect is achieved. In one embodiment, the data obtained from the assays can be used in formulating a range of dosage for use in humans. It will be understood by one of skill in the art that the when the composition comprises a compound of the invention (e.g. compounds of Formula I, compounds of

Formula A-I, compounds of Formula II, compounds of Formula A-II) and a β-lactam antibiotic, both the compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) and the β-lactam antibiotic are active compounds.

The method comprises administering to the subject an effective dose of one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably in conjunction with a β lactam antibiotic. An effective dose of a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) is generally between 125 mg/day to 2000 mg/day. In one embodiment, an effective dose is from about 0.1 to about 100 mg/kg of one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) or pharmaceutically acceptable salts thereof. In one embodiment, the dose is from about 0.1 to about 50 mg/kg of one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) or pharmaceutically acceptable salts thereof. In another embodiment, the dose is from about 1 to about 25 mg/kg of one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) or pharmaceutically acceptable salts thereof. In another embodiment, the dose is from about 1 to about 12 mg/kg of one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II). In another embodiment, the dose is about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 mg/kg of one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II). In another embodiment, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) are administered to a human at a dose of 100 mg to 1000 mg per dose up to four times per day. In another embodiment, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) are administered to a human at a dose of 125 mg to 750 mg per dose up to four times per day. In another embodiment, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) are administered to a human at a dose of 250 mg to 500 mg per dose up to four times a day. An

effective dose for cell culture is usually between about 0.1 and about 1000 μg/mL. In one embodiment, the effect dose for cell culture is between about 0.1 and about 200 μg/mL.

In one embodiment, a β-lactam antibiotic and a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) are administered in ratio of 1:4 to 8:1 antibiotic: compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II). In one embodiment the ratio is 1:4. In another embodiment the ratio is 3:4. In another embodiment the ratio is 5:4. In another embodiment the ratio is 7:4. In another embodiment the ratio is 1:2. In another embodiment the ratio is 3:2. In another embodiment the ratio is 5:2. In another embodiment the ratio is 7:2. In another embodiment the ratio is 1:3. In another embodiment the ratio is 2:3. In another embodiment the ratio is 4:3. In another embodiment the ratio is 5:3. In another embodiment the ratio is 7:3. In another embodiment the ratio is 1:2. In another embodiment the ratio is 3:2. In another embodiment the ratio is 5:2. In another embodiment the ratio is 7:2. In another embodiment the ratio is 1:1. In another embodiment the ratio is 2:1. In another embodiment the ratio is 3:1. In another embodiment the ratio is 4:1. In another embodiment the ratio is 5:1. In another embodiment the ratio is 6:1. In another embodiment the ratio is 7:1. In another embodiment the ratio is 8:1. It will be understood by one of skill in the art that the β-lactam antibiotic and compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) can be administered within the range of ratios provided regardless of the method of drug delivery. It will also be understood by one of skill in the art that the β-lactam antibiotic and compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) can be administered within the range of ratios provided together, for example, in a pharmaceutical composition, or sequentially, i.e. the β-lactam antibiotic is administered, followed by administration of a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) or vice versa.

One or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) may also be administered in the diet or feed of a patient or animal. If administered as part of a total dietary intake, the amount of compound employed can be less than 1% by weight of the diet,

such as no more than 0.5% by weight. The diet for animals can be normal foodstuffs to which the compound can be added or it can be added to a premix.

One or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, can be administered as a single daily dose or in multiple doses per day. In one embodiment, one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, is administered as a single dose per day. In another embodiment, one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I of Formula A-II in conjunction with a β-lactam antibiotic is administered as two equal doses per day. In another embodiment, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic is administered in three equal doses per day. In another embodiment, the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic is administered in four equal doses per day. The treatment regime may require administration over extended periods of time, e.g., for several days or for from two to four weeks. The amount per administered dose or the total amount administered will depend on such factors as the nature and severity of the infection, the age and general health of the patient, the tolerance of the patient to the compound of the invention and the β-lactam antibiotic and the microorganism or microorganisms involved in the infection. The treatment regimen for one type of infection may differ greatly from the treatment regimen of another infection. For example, one type of infection may require administration via intravenous administration once daily, while another infection may require a treatment regimen of multiple dosing orally.

One or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, may be administered according to this method until the bacterial infection is eradicated or reduced. In one embodiment, one or more compounds of the invention (e.g. compounds of Formula I,

compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, are administered for a period of time from 3 days to 6 months. In another embodiment, one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, are administered for 7 to 56 days. In another embodiment, one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, are administered for 7 to 28 days. In a further embodiment, one or more compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with a β-lactam antibiotic, are administered for 7 to 14 days. Compounds of the present invention may be administered for a longer or shorter time period if it is so desired.

Other embodiments of the invention include:

A pharmaceutical composition comprising a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II and at least 1 β-lactam antibiotic or a pharmaceutically acceptable salt thereof.

A pharmaceutical composition comprising a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II and at least 1 cephalosporin antibiotic or a pharmaceutically acceptable salt thereof.

A pharmaceutical composition comprising a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II and Ceftolozane or a pharmaceutically acceptable salt thereof.

A pharmaceutical composition comprising a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II and at least 1 carbapenem antibiotic or a pharmaceutically acceptable salt thereof.

A pharmaceutical composition comprising a compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds

of Formula A-II), preferably a compound of Formula A-I or Formula A-II and at least 1 monobactam antibiotic or a pharmaceutically acceptable salt thereof.

The embodiments described herein provide compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II that are novel and active β-lactamase inhibitors. Other embodiments described herein provide novel compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II in conjunction with β-lactam antibiotics for treatment of infections. Further embodiments described herein provide novel compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II), preferably a compound of Formula A-I or Formula A-II that show unexpected activity against β-lactamases that other compounds in the class do not have.

Preparation of Compounds of the Invention

A compound of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) can be prepared by a variety of synthetic routes, including synthetic schemes described herein. These synthetic routes can be applied to large scale synthesis with appropriate adjustment of reaction sequence, reaction conditions, isolation/purification methods and choice of solvents which are environmentally friendly and cost-effective.

The following abbreviations have the following meanings unless otherwise indicated. Abbreviations not defined below have their generally accepted meaning.

Bn	=	benzyl
Boc	=	*tert*-butoxycarbonyl
Boc_2O	=	di-*tert*-butyldicarbonate
Burgess reagent	=	methyl *N*-triethylammoniumsulfonyl)carbamate
CDI	=	carbonyldiimidazole
CFU	=	colony-forming units
CLSI	=	Clinical Laboratory Standards Institute
cSSSI	=	complicated skin and skin structure infections
DBU	=	1,8-diazabicyclo[5.4.0]undec-7-ene
DCM	=	dichloromethane
DEAD	=	diethyl azodicarboxylate

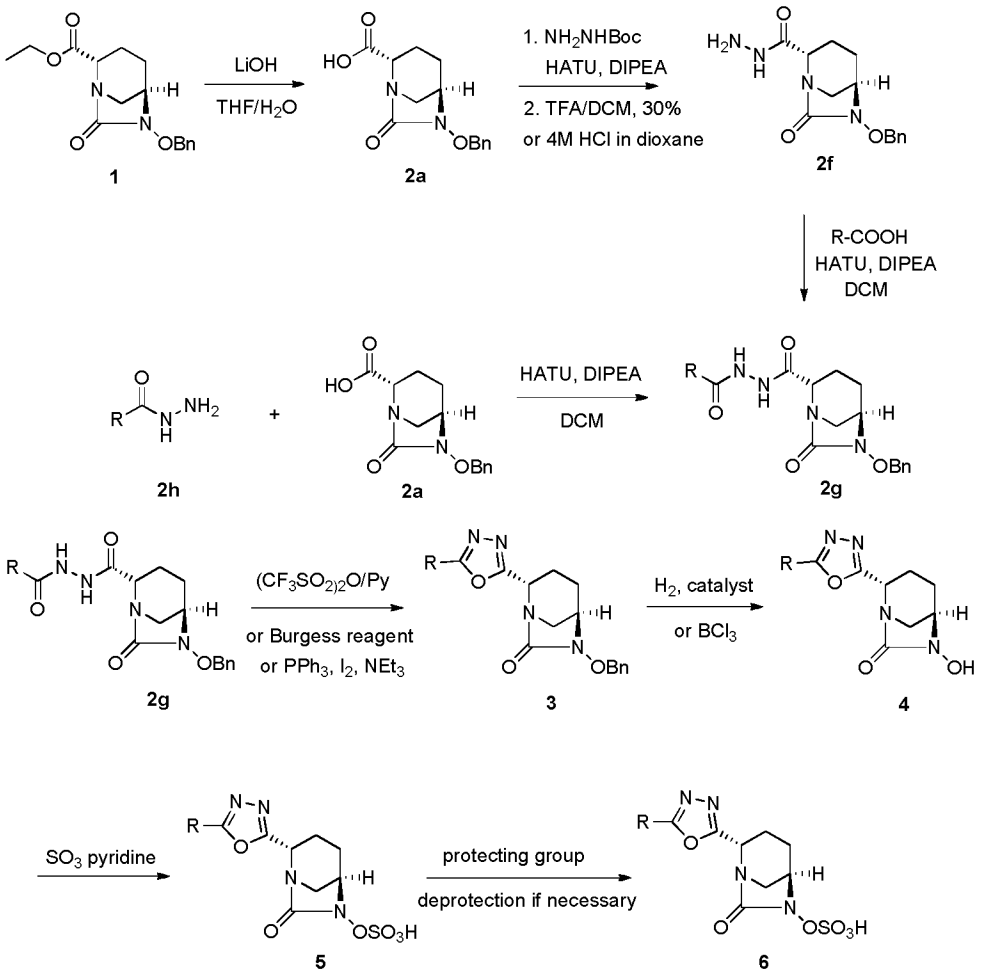
	DIAD	=	diisopropyl azodicarboxylate
	DIPEA	=	diisopropylethylamine
	DMF	=	N,N-dimethylformamide
	DMAc	=	N,N-dimethylacetamide
5	DMSO	=	dimethyl sulfoxide
	EDCI	=	1-ethyl-3-(3'-dimethylaminopropyl)carbodiimide
	ELSD	=	evaporative light scattering detector
	EtOAc	=	ethyl acetate
10	ESI-MS	=	electrospray ionization mass spectrometry
	Fmoc	=	Fluorenylmethyloxycarbonyl
	HAP	=	Hospital-Acquired Pneumonia
	HATU	=	2-(7-aza-1H-benzotriazole-1-yl)-1,1,3,3-tetramethyluronium hexafluorophosphate
15	HCl	=	hydrochloride
	HOBt	=	1-hydroxybenzotrizole
	Hrs	=	hours
	HPLC	=	high performance liquid chromatography
	Hunig's base	=	N,N-Diisopropylethylamine
20	Lawesson's reagent	=	2,4-bis(4-methoxyphenyl)-1,3,2,4-dithiadiphosphetane-2,4-disulfide
	MIC	=	minimum inhibitory concentration
	mL	=	milliliter
	MS	=	mass spectrometry
25	MRSA	=	methicillin-resistant *Staphylococcus aureus*
	NMR	=	nuclear magnetic resonance
	Ns	=	nitrobenzenesulfonyl
	Pa	=	*Pseudomonas aeruginosa*
	Prep	=	preparative
30	Ppm	=	parts per million
	Py	=	pyridine
	sat.	=	saturated
	rt	=	room temperature
	TBAF	=	tetrabutylammonium fluride

TBS	=	t-butyldimethylsilyl
TES	=	triethylsilyl
TEA	=	triethylamine
TEMPO	=	2,2,6,6-tetramethyl-1-piperidinyloxy, free radical
THF	=	tetrahydrofuran
TFA	=	trifluoroacetic acid
TMS	=	trimethylsilyl
TLC	=	thin layer chromatography
VAP	=	Ventilator-Associated Pneumonia

The compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) can be prepared from intermediate **1**, according to the following reaction schemes and examples, or modifications thereof, using readily available starting materials, reagents and conventional synthetic procedures including, for example, procedures described in US7112592 and WO2009/091856.

As depicted in Scheme 1, compound **3** can be synthesized following standard oxadiazole ring formation chemistry from the diacylhydrazide intermediate **2g** (see, e.g., Jakopin, Z.; Dolenc, M. S. *Curr. Org. Chem.* **2008**, *12*, 850-898; Walker, D. G.; Brodfuehrer, P. R.; Brundidge, S. P. Shih, K. M.; Sapino, C. Jr. *J. Org. Chem.* **1988,** *53*, 983-991 and references cited therein). Diacylhydrazide intermediate **2g** can be prepared via standard amide coupling reactions from acylhydrazide intermediate **2f.** Alternatively, **2g** can be made by an amide coupling reaction of acylhydrazine derivative **2h** and acid intermediate **2a,** which can be prepared from ester intermediate **1**. It may be necessary to protect certain functionalities in the molecule depending on the nature of the R^1 group. Protecting these functionalities should be within the expertise of one skilled in the art. See, e.g P. G. M. Wuts and T. W. Greene, *Protective Groups in Organic Synthesis,* Fourth Edition, John Wiley and Sons, 2006, hereafter Greene.

Scheme I

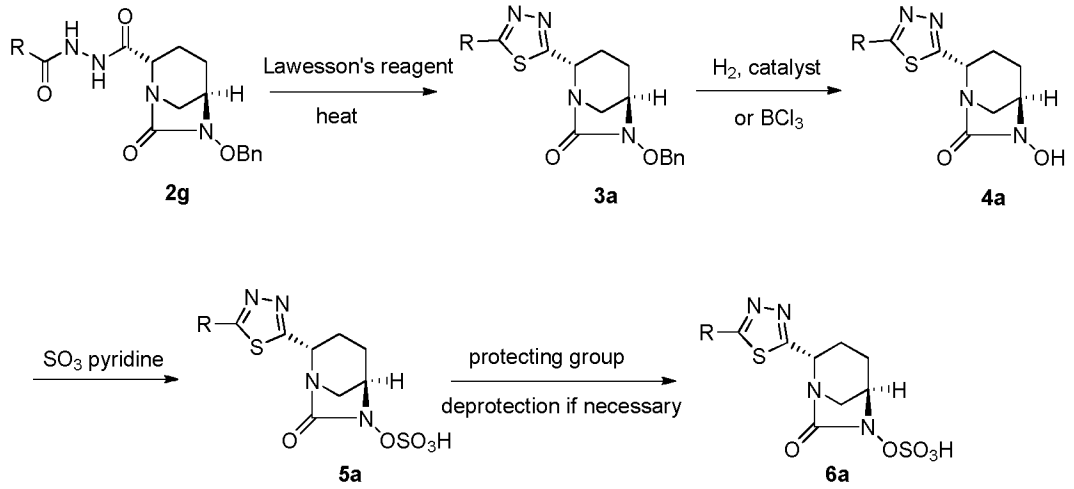


The benzylic ether protecting group in **3** can be removed via standard hydrogenolysis conditions, such as, but not limited to, Pd/H_2 in MeOH or THF or by acid-catalysed hydrolysis, such as, but not limited to, BCl_3 in DCM to provide the hydroxy-urea intermediate **4**, which can be used directly in the next step without further purification. Sulfation of **4** can be achieved by treatment with a sulfating reagent, such a, but not limited to, SO_3.pyridine complex, in an appropriate solvent, such as pyridine, DMF or DMAc at a temperature of 0-80 °C, preferable at room temperature. Compound **5** can then be isolated and purified via conventional methods. For example, **5** can be purified by standard reverse phase prep-HPLC using appropriate buffer system, i.e. ammonium formate buffer. In some cases, **5** can be purified by normal phase silica gel chromatography after converting to an appropriate salt form, such as sulfate tetrabutyl ammonium salt. The tetrabutyl ammonium salt can then be converted to a sodium salt by cation exchange. When a protecting group(s) is present in the sidechain (i.e. Boc or Fmoc for amine and guanidine protection, TBS or TES for alcohol protection, etc), a deprotection step is needed to convert **5** to its final product **6**,

which can be purified by prep-HPLC using the conditions mentioned above. For example, for *N*-Boc deprotection, **5** can be treated with an acid, such as TFA, in an appropriate solvent, such as DCM at a temperature of 0-30 °C, preferable at 0 °C to rt to give **6**. For an O-TBS, or O-TES deprotection, a fluoride reagent such as HF.pyridine, HF.NEt_3, or TBAF can be used. For Fmoc deprotection, amines can be used, such as diethylamine, DBU, piperidine, etc can be used.

Similarly, as shown in Scheme 2, thiadiazole derivative **3a** can be synthesized from diacylhydrazide intermediate **2g** by treatment with Lawesson's reagent under heating. **3a** can then be converted to the final product **6a** using similar chemistry as described previously.

Scheme 2



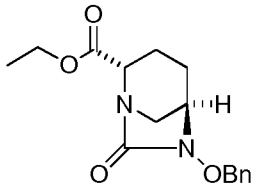
EXAMPLES

The specific examples which follow illustrate the synthesis of certain compounds. The methods disclosed may be adopted to variations in order to produce compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) but not otherwise specifically disclosed. Further, the disclosure includes variations of the methods described herein to produce the compounds of the invention (e.g. compounds of Formula I, compounds of Formula A-I, compounds of Formula II, compounds of Formula A-II) that would be understood by one skilled in the art based on the instant disclosure.

All temperatures are understood to be in Centigrade (C) when not specified. The nuclear magnetic resonance (NMR) spectral characteristics refer to chemical shifts (γ) expressed in parts per million (ppm) versus tetramethylsilane (TMS) as reference standard. The relative area reported for the various shifts in the proton NMR spectral data corresponds

to the number of hydrogen atoms of a particular functional type in the molecule. The nature of the shifts as to multiplicity is reported as broad singlet (br s), broad doublet (br d), singlet (s), multiplet (m), doublet (d), quartet (q), doublet of doublet (dd), doublet of triplet (dt), and doublet of quartet (dq). The solvents employed for taking NMR spectra are DMSO-d6 (perdeuterodimethysulfoxide), D_2O (deuterated water), $CDCl_3$ (deuterochloroform) and other conventional deuterated solvents. The prep-HPLC conditions are: Waters SunFire® C18 (30x100 mm, 5 μm OBD) column; flow rate: 30-80 mL/minute, ELSD or Mass-triggered fraction collection; sample loading: Each injection loading varied from - 300 mg for different crude samples depending on their solubility and purity profiles; Solvent system using ammonium formate buffer: solvent A: water with 20 mM ammonium formate, solvent B: 85% of acetonitrile in water with 20 mM ammonium formate. Solvent system using NH_4HCO_3 buffer: solvent A: water with 10 mM NH_4HCO_3, solvent B: acetonitrile. Solvent system using NH_4OH buffer: solvent A: water with 0.1% NH_4OH, solvent B: acetonitrile with 0.1% NH_4OH.

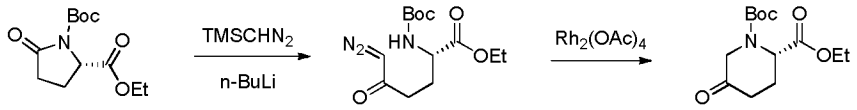
***Example 1**: Synthesis of (2S,5R)-ethyl 6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carboxylate (**Intermediate Compound 1**)*



1

Step 1: Synthesis of (S)-1-tert-butyl 2-ethyl 5-oxopiperidine-1,2-dicarboxylate

Method A:

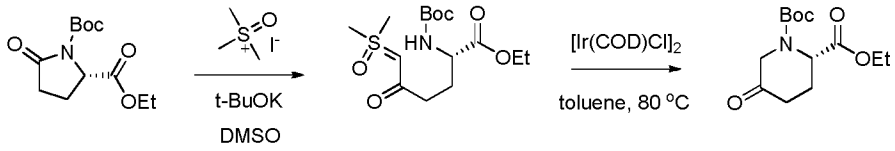


n-BuLi was added dropwise to a solution of $TMSCHN_2$ (690 mL, 1.38 mol) in dry THF (3 L) (600 mL, 1.5 mol) at -78 °C, and the mixture was stirred at -78 °C for 30 minutes. The mixture was then transferred to a solution of (*S*)-1-tert-butyl 2-ethyl 5-oxopyrrolidine-1,2-dicarboxylate (300 g, 1.17 mol) in dry THF (3 L) via cannula, and the mixture was stirred at -78 °C for 30 minutes. The reaction mixture was then quenched with sat. NH_4Cl solution, and extracted with DCM three times. The combined organic layer was concentrated in vacuum and the crude product was purified by silica gel column chromatography (3:1 petroleum

ether:EtOAc) to afford (*S*)-ethyl 2-((tert-butoxycarbonyl)amino)-6-diazo-5-oxohexanoate (262 g, 75 %) as a yellow solid.

A solution of (*S*)-ethyl 2-((*tert*-butoxycarbonyl)amino)-6-diazo-5-oxohexanoate (350 g, 1.18 mol) in DCM (1500 mL) was added to a solution of $Rh_2(OAc)_4$ (3.5 g, 7.9 mmol) in DCM (750 mL) at 0 °C. The reaction was then stirred at 20 °C overnight and then concentrated in vacuum. The crude sample was purified by silica gel column chromatography (5:1 petroleum ether/EtOAc) to afford (*S*)-1-tert-butyl 2-ethyl 5-oxopiperidine-1,2-dicarboxylate (175.9 g, 55%) as a yellow oil.

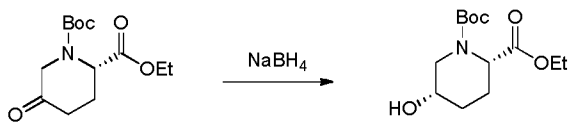
Method B:



t-BuOK (330 g, 2.9 mol) was added to a solution of trimethylsulfoxonium iodide (750 g, 3.5mol) in dry DMSO (3 L) and the mixture was stirred at rt for 1 h. (*S*)-1-tert-Butyl 2-ethyl 5-oxopyrrolidine-1,2-dicarboxylate (900 g, 3.5 mol) was added and the mixture was stirred at rt for 2-3 hrs. Water was added to quench the reaction and the mixture was extracted with EtOAc 5 times. The combined organic layer was concentrated in vacuum and the crude sample was purified by silica gel column chromatography (1:1petroleum ether/EtOAc then 1:10 MeOH/DCM) to afford sulfoxonium ylide intermediate (977 g, 80%) as a white solid.

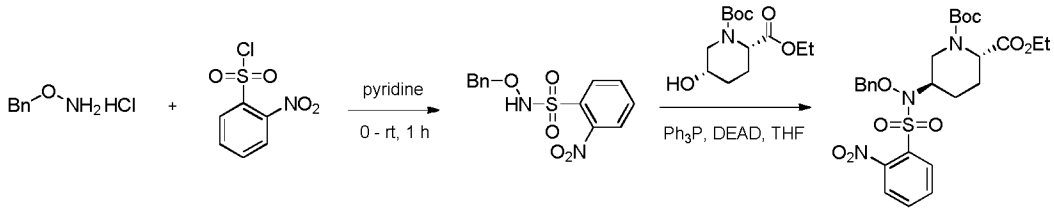
A solution of sulfoxonium ylide intermediate (156 g, 0.446 mol) and $[Ir(COD)Cl]_2$ (3 g, 4.46 mmol) in toluene(4 L) was degassed by bubbling nitrogen through the solution for 10 minutes. The reaction mixture was heated to 80-90 °C for 2-3 hrs and then cooled to 20 °C. Then toluene was concentrated in vacuum, the residue was purified by silica gel column chromatography (10:1 to 3:1 gradient petroleum ether/EtOA) to afford (*S*)-1-tert-butyl 2-ethyl 5-oxopiperidine-1,2-dicarboxylate (140 g, 57.8%) as a yellow oil.

Step 2: Synthesis of (2S,5S)-1-tert-butyl 2-ethyl 5-hydroxypiperidine-1,2-dicarboxylate



$NaBH_4$ (36 g, 1.0 mol) was added in portions to a solution of (*S*)-1-tert-butyl 2-ethyl 5-oxopiperidine-1,2-dicarboxylate (250 g, 0.92 mol) in EtOH (1500 mL) at -40 °C. The reaction mixture was then stirred at -40 °C for 0.5 hr then quenched with 10% HOAc solution. After diluting with water, the mixture was extracted with DCM three times. The combined organic layer was concentrated in vacuum and purified by silica gel column chromatography (1:1 petroleum ether/EtOAc) to afford (2*S*,5*S*)-1-tert-butyl 2-ethyl 5-hydroxypiperidine-1,2-dicarboxylate (205 g, 80%) as a yellow oil.

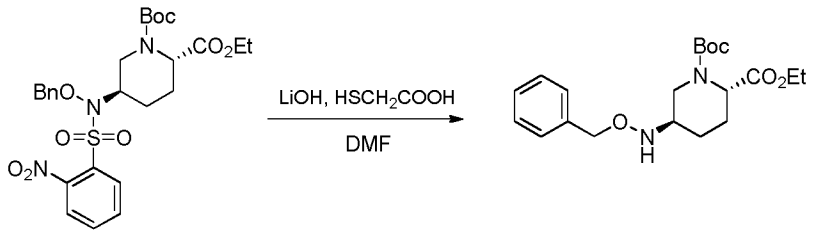
Step 3: Synthesis of (2S,5R)-1-tert-butyl 2-ethyl 5-(N-(benzyloxy)-2-nitrophenylsulfonamido)piperidine-1,2-dicarboxylate



A solution of 2-nitrobenzene-1-sulfonyl chloride (500 g, 2.26 mol) in pyridine (1500 mL) was added dropwise to a solution of *O*-benzylhydroxylamine hydrochloride (400 g, 2.51 mol) in pyridine (1500 mL) at 0 °C. The reaction mixture was then stirred at 20 °C overnight. The mixture was concentrated in vacuum, diluted with DCM and washed with HCl (10%) three times. The combined organic layer was concentrated in vacuum and re-crystallized with DCM to afford *N*-(benzyloxy)-2-nitrobenzenesulfonamide (485 g, 62.6%) as a yellow solid.

To a solution of *N*-(benzyloxy)-2-nitrobenzenesulfonamide (212 g, 0.69 mol) in THF (1000 mL) was added (2*S*,5*S*)-1-tert-butyl 2-ethyl 5-hydroxypiperidine-1,2-dicarboxylate (171 g, 0.63 mol) and PPh_3 (275 g, 1.05 mol), followed by dropwise addition of a solution of DEAD (195 g, 1.12 mol) in THF (500 mL). The mixture was then stirred at 20 °C overnight. The reaction mixture was then concentrated in vacuum and purified by silica gel column chromatography (3:1 petroleum ether/EtOAc) to afford (2*S*,5*R*)-1-tert-butyl 2-ethyl 5-(*N*-(benzyloxy)-2-nitrophenylsulfonamido)piperidine-1,2-dicarboxylate (283.8 g, 80%) as a yellow oil.

Step 4: Synthesis of (2S,5R)-1-tert-butyl 2-ethyl 5-((benzyloxy)amino)piperidine-1,2-dicarboxylate



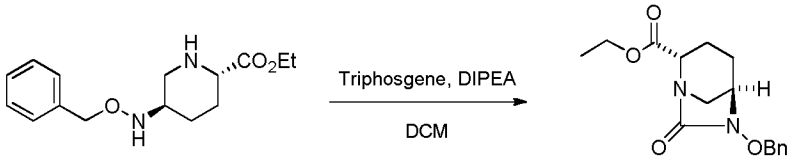
$LiOH{\cdot}H_2O$ (95 g, 2.3 mol) and 2-mercaptoacetic acid (124 g, 1.3 mol) were added to a solution of (2*S*,5*R*)-1-tert-butyl 2-ethyl 5-(*N*-(benzyloxy)-2-nitrophenylsulfonamido)piperidine-1,2-dicarboxylate (251 g, 0.45 mol) in DMF (1200 mL) . The reaction mixture was then stirred at 20 °C overnight. The reaction mixture was diluted with water and extracted with EtOAc (3x). The combined organic layer was washed with brine (3x), concentrated in vacuum and purified by silica gel column chromatography (3:1 petroleum ether/EtOAc) to afford (2*S*,5*R*)-1-tert-butyl 2-ethyl 5-((benzyloxy)amino)piperidine-1,2-dicarboxylate (122.9 g, 85%) as a yellow solid.

Step 5: Synthesis of (2S,5R)-ethyl 5-((benzyloxy)amino)piperidine-2-carboxylate



TFA (600 mL) was added to a solution of (2*S*,5*R*)-1-tert-butyl 2-ethyl 5-((benzyloxy)amino)piperidine-1,2-dicarboxylate (263 g, 0.7 mol) in DCM (600 mL) at 20 °C. The mixture was stirred at rt overnight and then concentrated in vacuum. The crude product was adjusted to pH 10 with sat. $NaHCO_3$ solution, and then extracted with DCM three times. The combined organic layer was concentrated in vacuum and purified by silica gel column chromatography (20:1 DCM/MeOH) to afford (2*S*,5*R*)-ethyl 5-((benzyloxy)amino)piperidine-2-carboxylate (184.9 g, 95%) as a yellow oil.

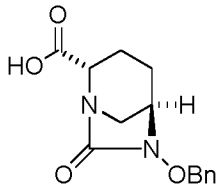
Step 6: Synthesis of (2S,5R)-ethyl 6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carboxylate



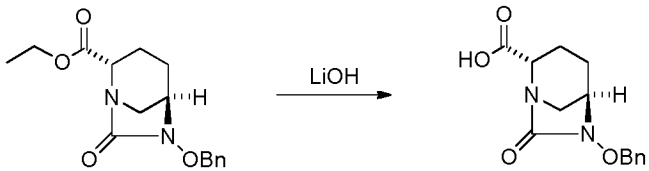
Triphosgene (21.3 g, 72 mmol) was added in portions to a solution of (2*S*,5*R*)-ethyl 5-((benzyloxy)amino)piperidine-2-carboxylate (50 g, 0.18 mol) and DIPEA (128 mL, 0.72 mol)

in DCM (2000 mL) at 0 °C . After stirring at 20 °C overnight, the reaction mixture was washed with H_3PO_4 (10%), sat. $NaHCO_3$ and saturated NaCl. The combined organic layer was concentrated in vacuum and purified by silica gel column chromatography (3:1 petroleum ether/EtOAc) to afford (2*S*,5*R*)-ethyl 6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carboxylate (27.4 g, 50%) as a yellow solid. ^{1}H NMR (400Mz, $CDCl_3$): δ 7.43-7.36 (m, 5H), 5.06 (d, *J* = 11.4 Hz, 1H), 4.90 (d, *J* = 11.4 Hz, 1H), 4.24 (q, *J* = 7.1 Hz, 2H), 4.11-4.08 (m, 1H), 3.32-3.31 (m, 1H), 3.08-3.05 (m, 1H), 2.93 (d, *J* = 11.9 Hz, 1H), 2.14-2.05 (m, 2H), 2.05-2.00 (m, 1H), 1.71-1.63 (m, 1H), 1.29 (t, *J* = 7.1 Hz, 3H).

***Example 2**: Synthesis of (2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carboxylic acid (**Intermediate Compound 2a**)*

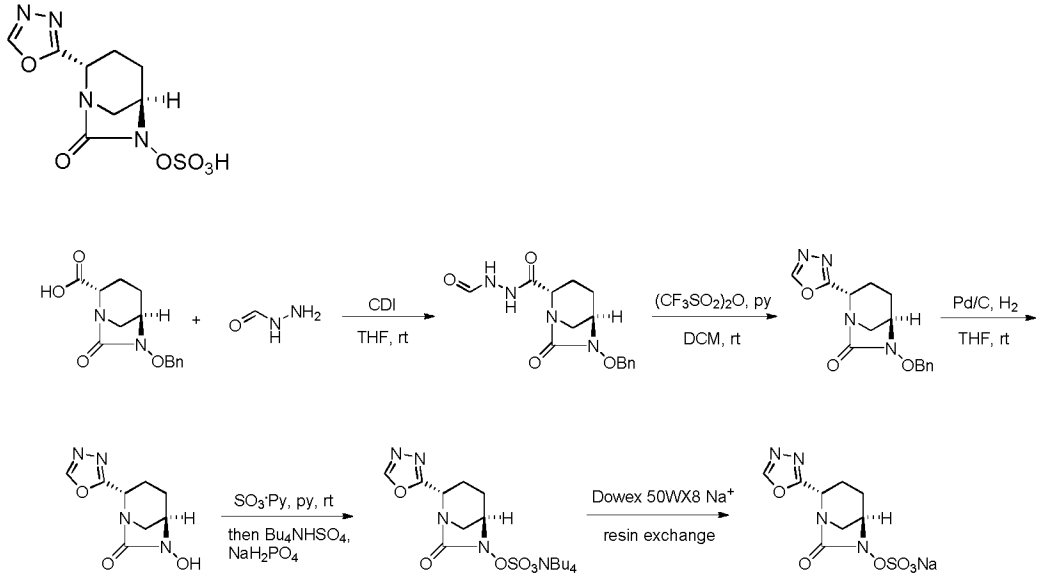


2a



LiOH (1.2 g, 29.6 mmol) was added to a solution of (2*S*,5*R*)-ethyl 6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carboxylate (9 g, 29.6 mmol) in THF/H_2O (3:1, 240 mL). The mixture was then stirred at rt overnight. The reaction mixture was washed with EtOAc twice, then the aqueous solution was adjusted pH 2-3 with 1N HCl. The resulting mixture was extracted with DCM three times, and the combined organic layer was dried over saturated Na_2SO_4 and concentrated in vacuum to provide (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carboxylic acid (7.0 g, 77.7%), which was directly used in the next step without further purification. ESI-MS (EI^+, m/z): 277.31. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.49-7.29 (m, 5H), 5.06 (d, *J* = 11.4 Hz, 1H), 4.91 (d, *J* = 11.4 Hz, 1H), 4.15-4.10 (m, 1H), 3.36-3.34 (m, 1H), 3.15-3.11 (m, 1H), 2.83 (d, *J* = 11.8 Hz, 1H), 2.32-2.15 (m, 1H), 2.11-2.01 (m, 2H), 1.74-1.56 (m, 1H).

***Example 3**: Synthesis of (2S,5R)-2-(1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 701**)*



Step 1: 1,1'-Carbonyldiimidazole (5.8 g, 36.2 mmol) was added to a 0 °C solution of (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carboxylic acid (5.0 g, 18.1 mmol) in dry THF (200 mL). The reaction mixture was allowed to warm to rt then was stirred at rt for 3 hrs. Formohydrazide (5.4 g, 90.5 mmol) was added in one portion, and the reaction mixture was stirred for additional 3 hrs. The mixture was then diluted with saturated sodium chloride and exatracted with EtOAc (3x). The combined organic layer was washed with saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated to afford crude (2*S*,5*R*)-6-(benzyloxy)-*N*'-formyl-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbohydrazide (~11 g), which was directly used in the next step. ESI-MS (EI^+, *m/z*): 319.1 $[M+H]^+$.

Step 2: To a -10 °C solution of (2*S*,5*R*)-6-(benzyloxy)-*N*'-formyl-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbohydrazide (11 g) in dry DCM (200 mL) was added pyridine (28 mL), followed by dropwise addition of $(CF_3SO_2)_2O$ (28 mL). The reaction mixture was allowed to warm to rt and was stirred for 3 hrs. The reaction mixture was then cooled to -10 °C and quenched with sat. $NaHCO_3$. The organic layer was separated and the aqueous layer was extracted with EtOAc (3x). The combined organic layer was dried over Na_2SO_4, concentrated and purified by silica gel column chromatography (gradient elution 1:3 to 2:1 EtOAc/hexanes) to give (2*S*,5*R*)-6-(benzyloxy)-2-(1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-7-one (4.6 g, 86% for two steps) as a slightly yellow solid. ESI-MS

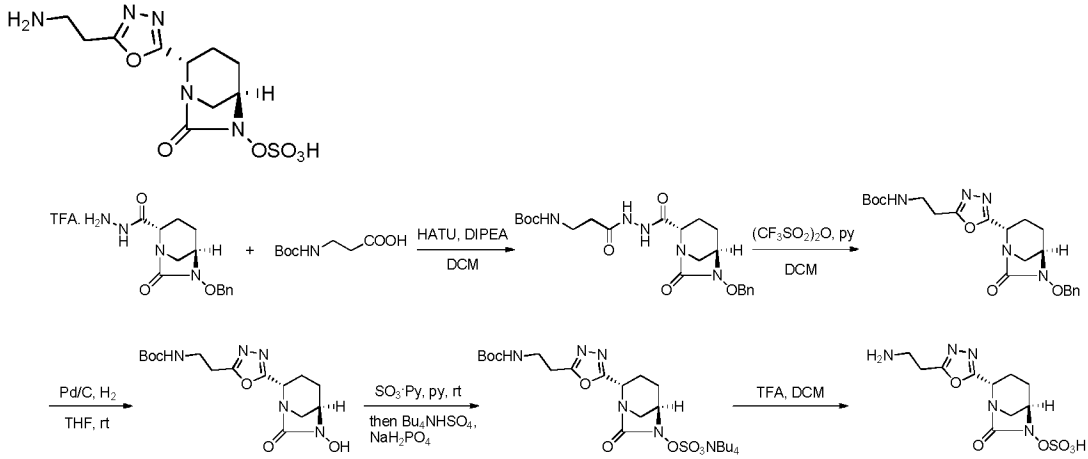
(EI$^+$, *m/z*): 301.0 $[M+H]^+$.

Step 3: To a solution of (2*S*,5*R*)-6-(benzyloxy)-2-(1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-7-one (4.6 g, 15.3 mmol) in THF (150 mL) was added 10% Pd/C (1 g). The mixture was stirred under H_2 atmosphere at rt for 3 hrs. The reaction mixture was then filtered and concentrated to afford (2*S*,5*R*)-6-hydroxy-2-(1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-7-one (2.9 g, 91 %), which was used directly in the next step. ESI-MS (EI$^+$, *m/z*): 211.1 $[M+H]^+$.

Step 4: To a solution of (2*S*,5*R*)-6-hydroxy-2-(1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-7-one (2.9 g, 13.8 mmol) in dry pyridine (60 mL) was added SO_3·Py (11.0 g, 69.0 mmol). The reaction mixture was stirred at rt for 8 hrs and then concentrated under vacuum. The residue was re-dissolved in aqueous NaH_2PO_4 (1.5 M, 100 mL) then tetrabutylammonium hydrogensulphate (5.88 g, 17.3 mmol) was added. The mixture was stirred at rt for 20 minutes, then was extracted with EtOAc (4x). The combined organic layer was dried and concentrated and the residue was purified by silica gel column chromatography (gradient elution 10:1 to 2:1 DCM/acetone) to afford tetrabutylammonium (2*S*,5*R*)-2-(1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate (4.1 g, 97%) as a white solid. ESI-MS (EI$^-$, *m/z*): 289.0 $[M-H]^-$. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.48 (s, 1H), 4.75 (d, J = 6.5 Hz, 1H), 4.40 (br s, 1H), 3.34-3.26 (m, 9H), 2.82 (d, J = 12.0 Hz, 1H), 2.37-2.25 (m, 3H), 2.06-1.98 (m, 1H), 1.71-1.65 (m, 8H), 1.49-1.42 (m, 8H), 1.01 (t, J = 7.5 Hz, 12H).

Step 5: Resin Exchange: Tetrabutylammonium (2*S*, 5*R*)-2-(1, 3, 4-oxadiazol-2-yl)-7-oxo-1, 6-diaza-bicyclo[3.2.1]octan-6-yl sulfate (4.1 g, 7.72 mmol) was dissolved in a minimum amount of HPLC grade water (~ 40 mL) and passed through a column of 80 g of DOWEX 50WX 8 Na^+ resin (the resin was prewased with >4 L of HPLC grade water) and eluted with HPLC grade water to afford sodium (2*S*,5*R*)-2-(1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate (2.2 g, 91%) as a white solid after lyophilization. ESI-MS (EI$^+$, *m/z*): 291.2 $[M+H]^+$. ^{1}H NMR (300 MHz, D_2O) δ 8.92 (s, 1H), 4.84 (d, J = 6.7 Hz, 1H), 4.20 (br s, 1H), 3.25-3.16 (m, 1H), 2.92 (d, J = 12.3 Hz, 1H), 2.41-2.26 (m, 1H), 2.26-2.11 (m, 2H), 2.04-1.89 (m, 1H).

***Example 4**: Synthesis of (2S,5R)-2-(5-(2-aminoethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 703**)*



Step 1: DIPEA (1.1 g, 8.3 mmol) was added to a 0 °C solution of (2*S*, 5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]ctane-2-carbohydrazide (1.0 g, 2.48 mmol) in DMF (10 mL). 3-((tert-Butoxycarbonyl)amino)propanoic acid (0.39 g, 2.07 mmol) and HATU (0.90 g, 2.48 mmol) were then added. The reaction mixture was stirred at 0 °C for 1 h and then quenched with saturated sodium chloride (50 mL). The organic layer was separated and the aqueous layer was exacted with EtOAc (3x). The combined organic layer was washed with saturated sodium chloride (2x), dried overNa_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (gradient elution 10:1 to 2:1 hexanes/EtOAc) to afford tert-butyl (3-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-3-oxopropyl)carbamate (1.0 g，87%). ESI-MS (EI^+, *m/z*): 462 $[M+H]^+$.

Step 2: $(CF_3SO_2)_2O$ (1.0 mL) was slowly added to a -10 °C solution of *tert*-butyl (3-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-3-oxopropyl)carbamate (1.0 g，2.17 mmol) and pyridine (1.0 mL) in dry DCM (10 mL). The reaction mixture was allowed to warm to rt and then was stirred at rt for 1 h. Then saturated $NaHCO_3$ was added at 0 °C very slowly. The organic layer was separated and the aqueous layer was exacted with EtOAc (3x). The combined organic layer was dried over $Na_2SO_4$and concentrated. The residue was purified by silica gel column chromatography (gradient elution 10:1 to 4:1 petroleum ether/EtOAc) to give *tert*-butyl (2-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate (0.40 g, 42%)

as a slight yellow solid. ESI-MS (EI^+, *m/z*): 444 $[M+H]^+$. ^1H NMR (500 MHz, DMSO-d_6) δ 7.48-7.46 (m, 2H), 7.45-7.37 (m, 3H), 6.99 (t, *J* = 5.5 Hz, 1H), 4.99-4.94 (m, 2H), 4.59 (d, *J* = 7.0 Hz, 1H), 3.73 (br s, 1H), 3.32-3.26 (m, 2H), 2.96-2.92 (m, 2H), 2.85-2.81 (m, 2H), 2.19-2.15 (m, 1H), 2.05-1.99 (m, 2H), 1.86-1.83 (m, 1H), 1.34 (s, 9H).

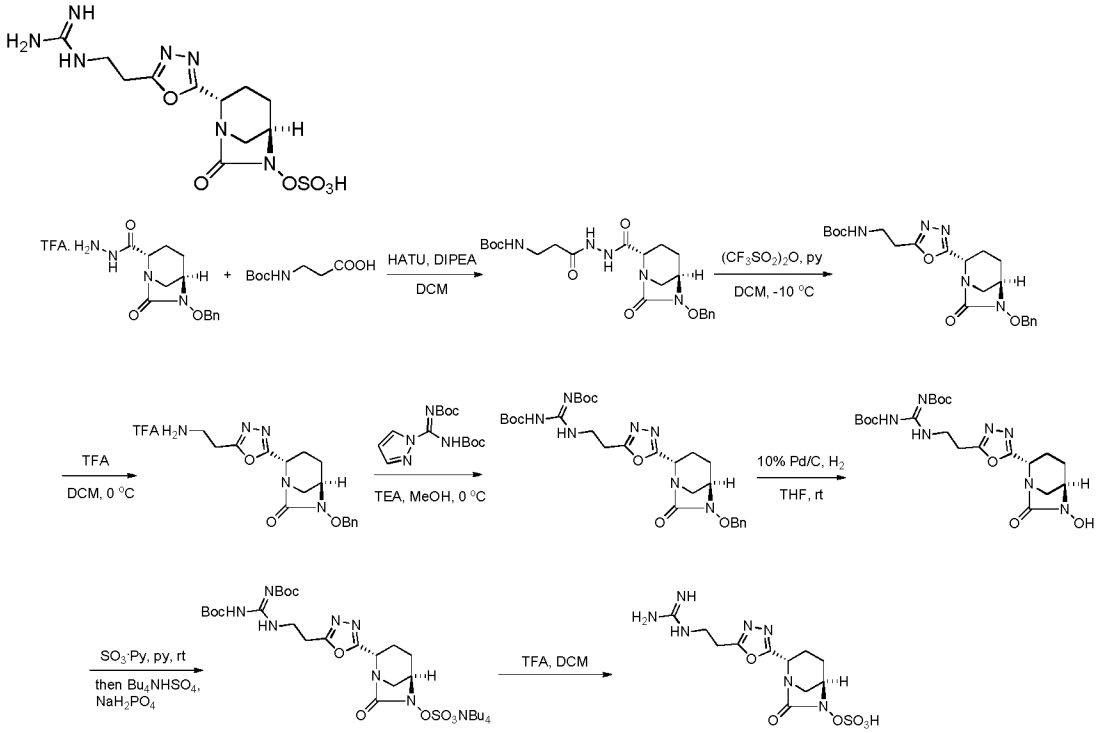
Step 3: A mixture of *tert*-butyl (2-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate (400 mg, 0.90mmol) and 10% Pd/C (50 mg) in THF (20 mL) was stirred under H_2 atmosphere at rt for 3 h. The reaction mixture was then filtered and concentrated to afford *tert*-butyl (2-(5-((2*S*,5*R*)-6-hydroxy-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate (300 mg, 94%) as a white solid, which was used directly in the next step. ESI-MS (EI^+, *m/z*): 354.24 $[M+H]^+$.

Step 4: To a solution of *tert*-butyl (2-(5-((2*S*,5*R*)-6-hydroxy-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate (300 mg, 0.85 mmol) in dry pyridine (4.0 mL) was added SO_3·Py (542 mg, 3.4 mmol). The mixture was stirred at rt overnight and then concentrated under vacuum. The residue was re-dissolved in aqueous NaH_2PO_4 (1.5 M, 20 mL) then tetrabutylammonium hydrogensulphate (345 mg, 1.02 mmol) was added. The mixture was stirred at rt for 20 minutes, then extracted with EtOAc (4x). The combined organic layer was dried and concentrated and the residue was purified by silica gel column chromatography (gradient elution 10:1 to 1:1 DCM/acetone) to afford tetrabutylammonium (2*S*,5*R*)-2-(5-(2-((tert-butoxycarbonyl)amino)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate (286 mg, 50%) as a white solid. ESI-MS (EI^+, *m/z*): 434.22 $[M+H]^+$.

Step 5: TFA (0.80 mL) was added to a 0 °C solution of tetrabutylammonium (2*S*,5*R*)-2-(5-(2-((*tert*-butoxycarbonyl)amino)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate (238 mg, 0.71 mmol) in dry DCM (2.0 mL). The reaction mixture was stirred at 0 °C for 30 minutes to 1 h and then diluted with ether. The precipitate was collected via centrifugation, washed with ether (3x) and further dried under high vacuum. The crude product TFA salt was purified by prep-HPLC using ammonium formate buffer to provide (2*S*,5*R*)-2-(5-(2-aminoethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (75 mg, 32%) as a white solid. ESI-MS (EI^+,

m/z): 334.1. ^{1}H NMR (300 MHz, D_2O) δ 4.78 (d, *J* = 6.2 Hz, 1H), 4.19 (br s, 1H), 3.44 (t, *J* = 6.0 Hz, 2H), 3.31 (t, *J* = 6.0 Hz, 2H), 3.20 (br d, *J* = 12.8 Hz, 1H), 2.96 (d, *J* = 12.3 Hz, 1H), 2.35-2.23 (m, 1H), 2.23-2.08 (m, 2H), 2.01-1.87 (m, 1H).

***Example 5**: Synthesis of (2S,5R)-2-(5-(2-guanidinoethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 705**)*



Step 1: DIPEA (1.1 g, 8.3 mmol) was added to a 0 °C solution of (2*S*, 5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbohydrazide (1.0 g, 2.48 mmol) in DMF (10 mL). 3-((*tert*-Butoxycarbonyl)amino)propanoic acid (0.39 g, 2.07 mmol) and HATU (0.90 g, 2.48 mmol) were then added. The reaction mixture was stirred at 0 °C for 1 h and then was quenched with saturated sodium chloride (50 mL). The organic layer was separated and the aqueous layer was exacted with EtOAc (3x). The combined organic layer was washed with saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (gradient elution 10:1 to 2:1 hexanes/EtOAc) to afford *tert*-butyl (3-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-3-oxopropyl)carbamate (1.0 g，87%). ESI-MS (EI$^+$, *m/z*): 462 $[M+H]^+$.

Step 2: $(CF_3SO_2)_2O$ (1.0 mL) was slowly added to a -10 °C solution of *tert*-butyl (3-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-3-oxopropyl)carbamate (1.0 g, 2.17 mmol) and pyridine (1.0 mL) in dry DCM (10 mL). The reaction mixture was allowed to warm to rt, was stirred at rt for 1 h then sat. $NaHCO_3$ was added at 0 °C very slowly. The organic layer was separated and the aqueous layer was exacted with EtOAc (3x). The combined organic layer was dried over Na_2SO_4 and concentrated. The residue was purified by silica gel column chromatography (gradient elution 10:1 to 4:1 petroleum ether/EtOAc) to give *tert*-butyl (2-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate (0.40 g, 42%) as a slight yellow solid. ESI-MS (EI^+, *m/z*): 444 $[M+H]^+$. ^1H NMR (500 MHz, DMSO-d_6) δ 7.48-7.46 (m, 2H), 7.45-7.37 (m, 3H), 6.99 (t, *J* = 5.5 Hz, 1H), 4.99-4.94 (m, 2H), 4.59 (d, *J* = 7.0 Hz, 1H), 3.73 (br s, 1H), 3.32-3.26 (m, 2H), 2.96-2.92 (m, 2H), 2.85-2.81 (m, 2H), 2.19-2.15 (m, 1H), 2.05-1.99 (m, 2H), 1.86-1.83 (m, 1H), 1.34 (s, 9H).

Step 3: TFA (0.5 mL) was added to a 0 °C solution of *tert*-butyl 2-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethylcarbamate (85 mg, 0.192 mmol) in CH_2Cl_2 (2.0 mL). The reaction mixture was stirred at 0 °C for 2 hrs and was then concentrated under vacuum to provide (2*S*,5*R*)-2-(5-(2-aminoethyl)-1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one TFA salt as a sticky oil, which was used directly in the next step. ESI-MS (EI^+, *m/z*): 344.2 $[M+H]^+$.

Step 4: TEA (77 mg, 0.764 mmol) was added to a 0 °C solution of (2*S*,5*R*)-2-(5-(2-aminoethyl)-1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one TFA salt from the previous step in MeOH (3.0 mL). Tert-Butyl (((tert-butoxycarbonyl)amino)(1H-pyrazol-1-yl)methylene)carbamate (65 mg, 0.209 mmol) was then added at 0 °C and the reaction mixture was stirred at 0 °C for 4 hrs. The reaction mixture was evaporated and the residue was purified by silica gel column chromatography (gradient elution 30%-50% EtOAc/petroleum ether) to give (2*S*,5*R*)-2-(5-((2,3-bis(*tert*-butoxycarbonyl)guanidino)ethyl)-1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one (80 mg, 70% in 2 steps) as a colorless oil. ESI-MS (EI^+, *m/z*): 586.3 $[M+H]^+$.

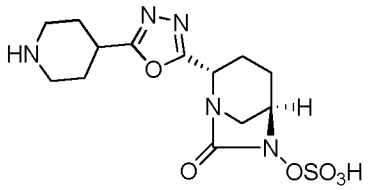
Step 5: To a solution of (2*S*,5*R*)-2-(5-((2,3-bis(*tert*-butoxycarbonyl)guanidino)ethyl)-1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one (80 mg, 0.136 mmol) in

THF (15 mL) was added 10% Pd/C (45 mg) and the mixture was stirred under H_2 atmosphere at rt for 1 h. The reaction mixture was filtered and concentrated to afford (2*S*,5*R*)-6-hydroxy-2-(5-((2,3-bis(*tert*-butoxycarbonyl)guanidino)ethyl)-1,3,4-oxadiazol-2-yl)-1,6-diaza-bicyclo[3.2.1]octan-7-one, which was directly used in the next step. ESI-MS (EI^+, *m/z*): 496.2 $[M+H]^+$.

Step 6: To a solution of (2*S*,5*R*)-6-hydroxy-2-(5-((2,3-bis(*tert*-butoxycarbonyl)guanidino)ethyl)-1,3,4-oxadiazol-2-yl)-1,6-diaza-bicyclo[3.2.1]octan-7-one from the previous step in dry pyridine (2.0 mL) was added $SO_3 \cdot Py$ (152 mg, 0.962 mmol). The mixture was stirred at rt for 3 hrs and then concentrated under vacuum. The residue was re-dissolved in aqueous NaH_2PO_4 (1.5 M, 15 mL) then tetrabutylammonium hydrogensulphate (50 mg, 0.15 mmol) was added. The mixture was stirred at rt for 20 minutes, then extracted with EtOAc (4x). The combined organic layer was dried and concentrated and the residue was purified by silica gel column chromatography (gradient elution 10:1 to 3:1 DCM/acetone) to afford tetrabutylammonium (2*S*,5*R*)-2-(5-(2-(2,3-bis(tert-butoxycarbonyl)guanidino)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-6-yl sulfate (60 mg, 53%) as a white solid. ESI-MS (EI^-, *m/z*): 574.1 $[M-H]^-$.

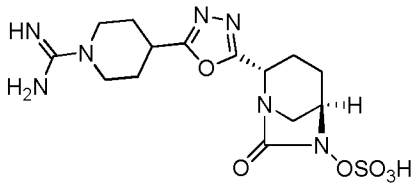
Step 7: TFA (0.23 mL) was added to a 0 °C solution of tetrabutylammonium (2*S*,5*R*)-2-(5-(2-(2,3-bis(*tert*-butoxycarbonyl)guanidino)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-6-yl sulfate (50 mg, 0.06 mmol) in dry DCM (0.68 mL). The reaction mixture was stirred at 0 °C for 2 h and then diluted with ether. The precipitate was collected via centrifugation, washed with ether (3x) and further dried under high vacuum to provide (2*S*,5*R*)-2-(5-(2-guanidinoethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate as TFA salt (~ 12 mg). ESI-MS (EI^+, *m/z*): 376.18. ^1H NMR (300 MHz, D_2O) 4.77 (d, $J = 6.7$ Hz, 1H), 4.19 (br s, 1H), 3.62 (t, $J = 6.4$ Hz, 2H), 3.21-3.18 (m, 1H), 3.18 (t, $J = 6.4$ Hz, 2H), 2.89 (d, $J = 12.3$ Hz, 1H), 2.32 -2.20 (m, 1H), 2.20-2.11 (m, 2H), 1.98-1.86 (m, 1H).

***Example 6**: Synthesis of (2S,5R)-7-oxo-2-(5-(piperidin-4-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 711**)*



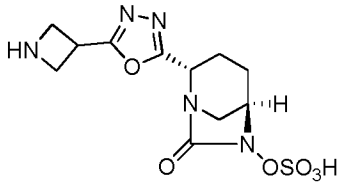
Following Steps 1-5 in Example 4, replacing 3-((*tert*-butoxycarbonyl)amino)propanoic acid in Step 1 with 1-(*tert*-butoxycarbonyl)piperidine-4-carboxylic acid, (2*S*,5*R*)-7-oxo-2-(5-(piperidin-4-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (89 mg) was obtained as a light yellow solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI$^+$, *m/z*): 374.26 ^{1}H NMR (300 MHz, D_2O) δ 4.77 (d, *J* = 5.9 Hz, 1H), 4.20 (br s, 1H), 3.52-3.33 (m, 3H), 3.25-3.09 (m, 3H), 2.92 (d, *J* = 12.3 Hz, 1H), 2.40-2.23 (m, 3H), 2.22-2.10 (m, 2H), 2.09-1.88 (m, 3H).

***Example 7**: Synthesis of (2S,5R)-2-(5-(1-carbamimidoylpiperidin-4-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 712**)*



Following Steps 1-7 in Example 5, replacing 3-((*tert*-butoxycarbonyl)amino)propanoic acid in Step 1 with 1-(*tert*-butoxycarbonyl)piperidine-4-carboxylic acid, (2*S*,5*R*)-2-(5-(1-carbamimidoylpiperidin-4-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (35 mg) was obtained as a light yellow solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI$^+$, *m/z*): 416.24. ^{1}H NMR (300 MHz, D_2O) δ 4.77 (d, *J* = 5.9 Hz, 1H), 4.19 (br s, 1H), 3.84-3.79 (m, 2H), 3.42-3.14 (m, 4H), 2.91 (d, *J* = 12.0 Hz, 1H), 2.36-2.07 (m, 5H), 2.05-1.75 (m, 3H).

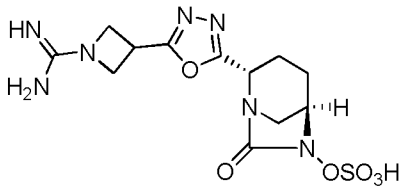
***Example 8**: Synthesis of (2S,5R)-2-(5-(azetidin-3-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 708**)*



Following Steps 1-5 in Example 4, replacing 3-((*tert*-butoxycarbonyl)amino)propanoic acid in Step 1 with 1-(*tert*-butoxycarbonyl)azetidine-3-carboxylic acid, (2*S*,5*R*)-2-(5-(azetidin-3-

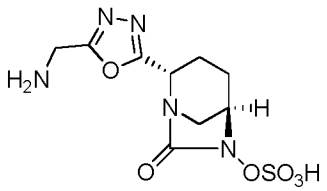
yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (18 mg) was obtained as a light yellow solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 346.17. ^1H NMR (300 MHz, D_2O) δ 4.81 (d, *J* = 6.6 Hz, 1H), 4.58-4.32 (m, 4H), 4.20 (s, 1H), 3.21 (br d, *J* = 12.1 Hz, 1H), 2.95 (d, *J* = 12.3 Hz, 1H), 2.30 (dt, *J* = 13.9, 6.8 Hz, 1H), 2.35-2.25 (m, 1H), 2.20-2.10 (m, 2H), 2.01-1.91 (m, 1H).

***Example 9**: Synthesis of (2S,5R)-2-(5-(1-carbamimidoylazetidin-3-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 709**)*



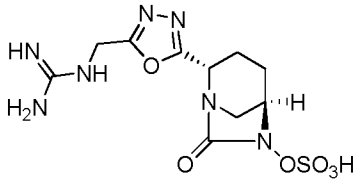
Following Steps 1-7 in Example 5, replacing 3-((*tert*-butoxycarbonyl)amino)propanoic acid in Step 1 with 1-(*tert*-butoxycarbonyl)azetidine-3-carboxylic acid, (2*S*,5*R*)-2-(5-(1-carbamimidoylazetidin-3-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (280 mg) was obtained as a light yellow solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 388.12. ^1H NMR (300 MHz, D_2O) δ 4.77 (br d, *J* = 6.2 Hz, 1H), 4.57-4.44 (m, 2H), 4.39-4.22 (m, 3H), 4.17 (br s, 1H), 3.18 (br d, *J* = 12.1 Hz, 1H), 2.91 (d, *J* = 12.3 Hz, 1H), 2.31-2.19 (m, 1H), 2.19-2.06 (m, 2H), 2.00-1.84 (m, 1H).

***Example 10**: Synthesis of (2S,5R)-2-(5-(aminomethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 702**)*



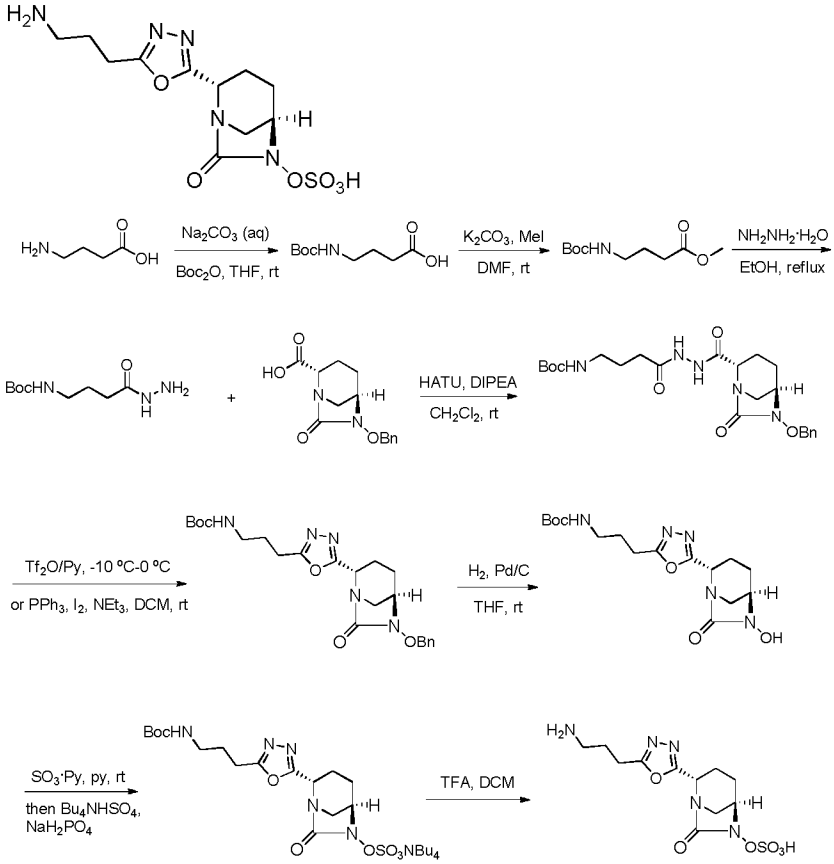
Following Steps 1-5 in Example 4, replacing 3-((*tert*-butoxycarbonyl)amino)propanoic acid in Step 1 with 2-((*tert*-butoxycarbonyl)amino)acetic acid, (2*S*,5*R*)-2-(5-(aminomethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (34 mg) as TFA salt. ESI-MS (EI^+, *m/z*): 320.16 .

***Example 11**: Synthesis of (2S,5R)-2-(5-(guanidinomethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 704**)*



Following Steps 1-7 in Example 5, replacing 3-((*tert*-butoxycarbonyl)amino)propanoic acid in Step 1 with 2-((*tert*-butoxycarbonyl)amino)acetic acid, (2*S*,5*R*)-2-(5-(guanidinomethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (745 mg) was obtained as a light yellow solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 362.2.

***Example 12**: Synthesis of (2S,5R)-2-(5-(3-aminopropyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 720**)*



Step 1: Synthesis of 4-(tert-butoxycarbonylamino)butanoic acid:

To an aqueous solution of 4-aminobutanoic acid (25 g, 242 mmol) in H_2O (500 mL) at rt was added Na_2CO_3 (75 g, 726 mmol), followed by Boc_2O (95 g, 435 mmol) in THF (200 mL). The reaction mixture was stirred at rt for 12 hrs then concentrated under reduced pressure.

The aqueous residue was extracted with Et_2O, then the aqueous layer was acidified to pH 4~5 with citric acid and extracted with EtOAc. The combined organic layer was dried over Na_2SO_4, and concentrated to afford 4-(*tert*-butoxycarbonylamino)butanoic acid (45 g, 90%) as a colorless oil. ESI-MS (EI^+, *m/z*): 226 $[M+Na]^+$.

Step 2: Synthesis of methyl 4-(tert-butoxycarbonylamino)butanoate:

To a solution of 4-(*tert*-butoxycarbonylamino)butanoic acid (7.0 g, 34.5 mmol) and K_2CO_3 (9.5 g, 68.9 mmol) in acetone (70 mL) was added MeI (7.5 g, 51.8 mmol) at rt. The reaction solution was stirred at 45 °C for 12 hrs. The mixture was washed with water and saturated sodium chloride, dried over Na_2SO_4, and concentrated to afford methyl 4-(*tert*-butoxycarbonylamino)butanoate (6.2 g, 83%) as a yellow oil. ESI-MS (EI^+, *m/z*): 240 $[M+Na]^+$.

Step 3: Synthesis of tert-butyl 4-hydrazinyl-4-oxobutylcarbamate:

To a solution of methyl 4-(*tert*-butoxycarbonylamino)butanoate (21.0 g, 96.8 mmol) in MeOH (180 mL) was added $NH_2NH_2.H_2O$ (28.0 g, 483mmol) at rt. The mixture was stirred at 65 °C for 12 hrs then concentrated under reduced pressure. The crude material was dissolved in DCM (400 mL). The organic layer was washed with water (2x), and saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated to afford *tert*-butyl 4-hydrazinyl-4-oxobutylcarbamate (18.9 g, 90%) as a white solid. ESI-MS (EI^+, *m/z*): 240 $[M+Na]^+$.

Step 4: Synthesis of tert-butyl4-(2-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-4-oxobutylcarbamate:

To a 0 °C solution of (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carboxylic acid (12.0 g, 43.5 mmol) and *tert*-butyl 4-hydrazinyl-4-oxobutylcarbamate (10.5 g, 47.8 mmol) in CH_2Cl_2 (360 mL) was added HATU (19.6 g, 52.2 mmol) and DIPEA (16.6 g, 130.5 mmol). The mixture was allowed to warm to rt, was stirred at rt for 12 hrs then diluted with CH_2Cl_2 (300 mL), washed with water (2x) and saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (gradient elution 50~80% EtOAc/petroleum ether) to afford *tert*-butyl 4-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo [3.2.1]octane-2-carbonyl)hydrazinyl)-4-oxobutylcarbamate (19.3 g, 93%) as a white solid. ESI-MS (EI^+, *m/z*): 476 $[M+H]^+$.

Step 5: Synthesis of tert-butyl 3-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)propylcarbamate:

Method A:

Tf_2O (8.0 mL, 0.0474 mol) was added dropwise to a -78 °C solution of *tert*-butyl 4-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo [3.2.1]octane-2-carbonyl)hydrazinyl)-4-oxobutylcarbamate (7.5 g, 0.0158 mol) and Py (10.2 mL, 0.126 mol) in dry DCM (120 mL). The reaction mixture was allowed to warm to 0 °C then the reaction mixture was stirred at 0 °C for 3 hrs. Sat. $NaHCO_3$ was added at 0 °C very slowly. The organic layer was separated and the water layer was exacted with DCM (3x). The combined organic layer was washed with water, saturated sodium chloride, dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column (gradient elution 0~25% EtOAc/petroleum ether) to afford *tert*-butyl 3-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)propylcarbamate (3.9 g, 54%) as a yellow solid. ESI-MS (EI^+, m/z): 458 $[M+H]^+$. ^1H NMR (500 MHz, $CDCl_3$) δ 7.45-7.37 (m, 5H), 5.08 (d, *J* = 14.5 Hz, 1H), 4.93 (d, *J* = 14.5 Hz, 1H), 4.70-4.66 (m, 1H), 3.37 (br s, 1H), 3.23-3.21 (m, 2H), 2.94-2.88 (m, 3H), 2.79 (d, *J* = 14.5 Hz, 1H), 2.30-2.28 (m, 2H), 2.11-1.97 (m, 4H), 1.45 (s, 9H).

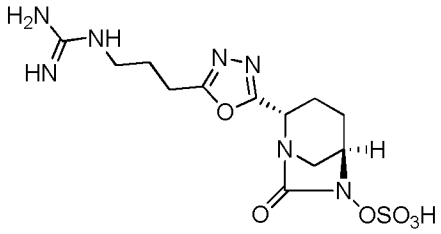
Method B:

To s solution of PPh_3 (2.6 g, 10.0 mmol) in dry DCM (60 mL) was added I_2 (2.6 g, 10.0 mmol). After I_2 was dissolved completely, TEA (3.5 mL, 25.0 mmol) was added quickly at rt. The mixture was stirred for 15 mins. *Tert*-butyl 4-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo [3.2.1]octane-2-carbonyl)hydrazinyl)-4-oxobutylcarbamate (2.4 g, 5.0 mmol) was added. The mixture was stirred at rt for 1 hr. The solvent was concentrated. EtOAc (250 mL) was added, and the solution was filtrated to remove $POPh_3$. The filtrate was concentrated. The resulting residue was purified by silica gel column chromatography (gradient elution 0~40% EtOAc/petroleum ether) to afford *tert*-butyl 3-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)propylcarbamate (2.0 g, 86%) as a white solid. ESI-MS (EI^+, m/z): 458 $[M+H]^+$.

Step 6-8: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate in Step 3 with *tert*-butyl (3-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-

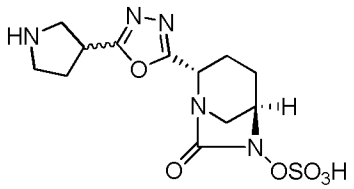
yl)-1,3,4-oxadiazol-2-yl)propyl)carbamate; (2*S*,5*R*)-2-(5-(3-aminopropyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (1.48 g) was obtained as a white solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 348.1. ^1H NMR (300 MHz, D_2O) δ 4.74 (d, *J* = 6.2 Hz, 1H), 4.17 (br s, 1H), 3.17 (br d, *J* = 12.1 Hz, 1H), 3.05 – 2.95 (m, 4H), 2.89 (d, *J* = 12.3 Hz, 1H), 2.31 – 2.20 (m, 1H), 2.20 – 2.02 (m, 4H), 2.00 – 1.82 (m, 1H).

***Example 13**: Synthesis of (2S,5R)-2-(5-(3-guanidinopropyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 714**)*



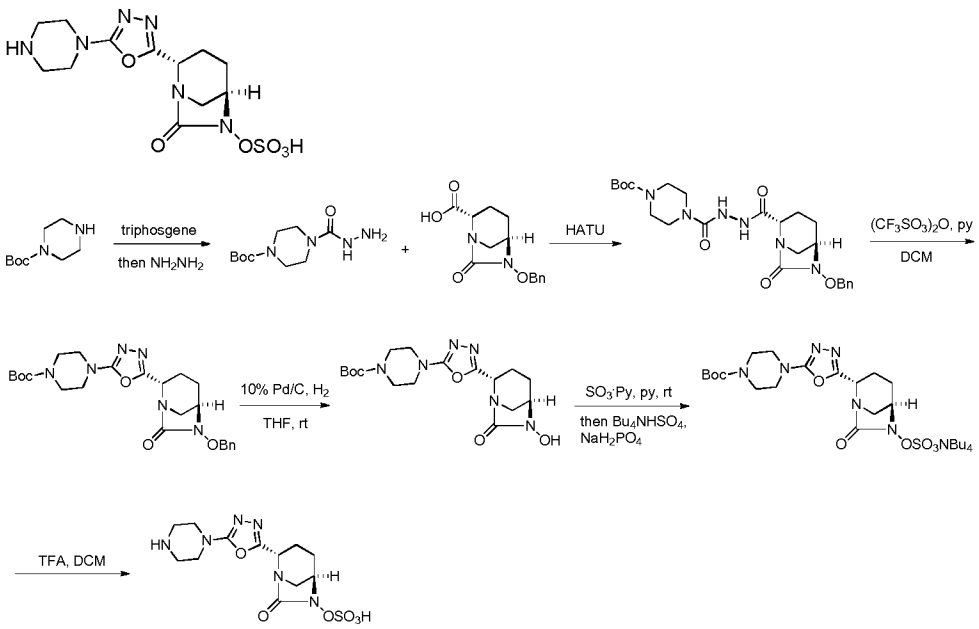
Following Steps 1-7 in Example 5, replacing 3-((*tert*-butoxycarbonyl)amino)propanoic acid in Step 1 with 4-((*tert*-butoxycarbonyl)amino)butanoic acid, (2S,5R)-2-(5-(3-guanidinopropyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (42 mg) was obtained as a light yellow solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 390.13.

***Example 14**: Synthesis of (2S,5R)-7-oxo-2-(5-(pyrrolidin-3-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 710**)*



Following Steps 1-5 in Example 4, replacing 3-((*tert*-butoxycarbonyl)amino)propanoic acid in Step 1 with 1-(*tert*-butoxycarbonyl)pyrrolidine-3-carboxylic acid, (2*S*,5*R*)-7-oxo-2-(5-(pyrrolidin-3-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (20 mg) was obtained as TFA salt. ESI-MS (EI^+, *m/z*): 360.20. ^1H NMR (300 MHz, D_2O) δ 4.78 (d, *J* = 6.5 Hz, 1H), 4.20 (br s, 1H), 4.05-3.94 (m, 1H), 3.80-3.73 (m, 1H), 3.66-3.60 (m, 1H), 3.53-3.38 (m, 2H), 3.20 (br d, *J* = 12.5 Hz, 1H), 2.94 (d, *J* = 12.3 Hz, 1H), 2.59-2.48 (m, 1H), 2.40-2.26 (m, 2H), 2.23-2.08 (m, 2H), 2.00-1.90 (m, 1H).

***Example 15**: Synthesis of (2S,5R)-7-oxo-2-(5-(piperazin-1-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 713**)*



Step 1: DIPEA (105 g, 0.81mol) was added to a 0 °C solution of *tert*-butyl piperazine-1-carboxylate (25.0 g, 0.134 mol) in DCM (250 mL), followed by the addition of triphosgene (92 g, 0.27 mol) in portions over a 40 minute time period. The reaction mixture was allowed to warm to rt then was stirred at rt for 3 hrs, filtered and concentrated to afford 1-*tert*-butyl 4-trichloromethyl piperazine-1,4-dicarboxylate (50 g) as an oil.

A solution of 1-*tert*-butyl 4-trichloromethyl piperazine-1,4-dicarboxylate (50 g, 0.145 mol) in THF (50 mL) was added dropwise over a 30 minute time period to a solution of hydrazine hydrate (18 mL, 0.434 mol) in THF (150 mL).The reaction mixture was stirred at rt for 2 hrs then diluted with saturated sodium chloride (50 mL) and exacted with EtOAc (3x). The combined organic layer was washed with saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated. The residue was purified by crystallization (3:1 petroleum ether/EtOAc) to provide *tert*-butyl 4-(hydrazinecarbonyl)piperazine-1-carboxylate (13 g, 40% for two steps). ESI-MS (EI^+, *m/z*): 245 $[M+H]^+$. ^{1}H-NMR (500 MHz, $CDCl_3$): δ5.92 (s, 1H), 3.45-3.35 (m, 8H), 1.41 (s, 9H).

Step 2: DIPEA (3.7 g, 10 mmol) was added to a 0 °C solution of (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carboxylic acid (1.45 g, 5.3 mmol, 0.8 eq.) and *tert*-butyl 4-(hydrazinecarbonyl)piperazine-1-carboxylate (1.6 g, 6.6 mmol) in dry DMF (50 mL),

followed by the addition of HATU (1.45 g, 5.3 mmol). The reaction mixture was allowed to warm to rt then was stirred at rt overnight. The mixture was then diluted with water (200 mL) and the resulting precipitated material was collected by filtration, rinsed with water, and then recrystalized (3:1 petroleum ether/EtOAc) to afford *tert*-butyl 4-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbonyl)hydrazinecarbonyl)piperazine-1-carboxylate (1.4 g, 54%), ESI-MS (EI^+, *m/z*): 503 $[M+H]^+$.

Step 3: To a solution of *tert*-butyl 4-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazine-carbonyl)piperazine-1-carboxylate (903 mg, 1.8 mmol) in DCM (200 mL) was added pyridine (2.8 mL, 36.0 mmol). $(CF_3SO_2)_2O$ (2.8 ml, 9.0 mmol) was then slowly added at -10 °C. The reaction mixture was stirred at rt for 3 hrs. Sat. $NaHCO_3$ was added at -10 °C very slowly. The organic layer was separated and the aqueous layer was exacted with EtOAc (3x). The combined organic layer was dried over Na_2SO_4 and concentrated. The crude product was purified by silica gel column chromatography (2:1 EtOAc/hexanes) to give *tert*-butyl 4-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)piperazine-1-carboxylate (723 mg, 83%) as a slight yellow solid. ESI-MS (EI^+, *m/z*): 485.2 $[M+H]^+$.

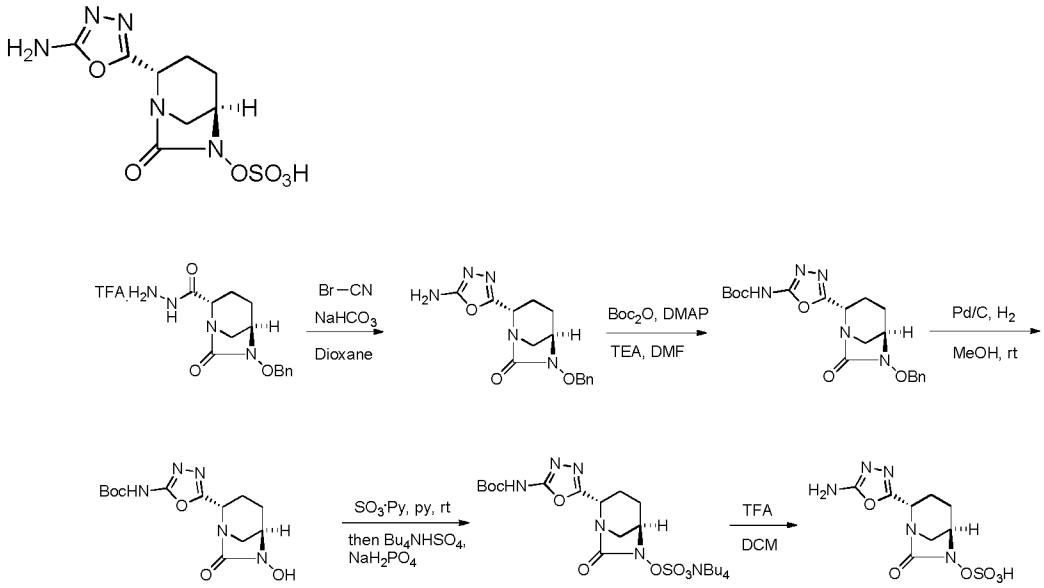
Step 4: To a solution of *tert*-butyl 4-(5-((2*S*,5*R*)-6-hydroxy-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)piperazine-1-carboxylate (50 mg, 0.1 mmol) in THF (5.0 mL) was added 10% Pd/C (20 mg). The mixture was stirred under H_2 atmosphere at rt for 3 hrs then filtered and concentrated to afford *tert*-butyl 4-(5-((2*S*,5*R*)-6-hydroxy-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)piperazine-1-carboxylate (30 mg, 75 %), which was used directly in the next step. ESI-MS (EI^+, *m/z*): 385 $[M+H]^+$.

Step 5: To a solution of *tert*-butyl 4-(5-((2*S*,5*R*)-6-hydroxy-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)piperazine-1-carboxylate (30 mg, 0.077 mmol) in dry pyridine (3 ml) was added $SO_3 \cdot Py$ (97 mg, 0.61 mmol). The mixture was stirred at rt for 3 hrs. The pyridine was evaporated under vacuum at 25 °C. The residue was re-dissolved in aqueous NaH_2PO_4 (1.5 M, 20 mL) and tetrabutylammonium hydrogensulphate (300 mg) was added. The mixture was stirred at rt for 20 minutes, then extracted with EtOAc (4x). The combined organic layer was dried and concentrated and the residue was purified by silica gel column chromatography (gradient elution 10:1 to 1:1

DCM/acetone) to give tetrabutylammonium (2*S*,5*R*)-2-(5-(4-(*tert*-butoxycarbonyl)piperazin-1-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate (20 mg, 20%). ESI-MS (EI⁻, *m/z*): 473 [M-H]⁻.

Step 6: TFA (0.30 mL) was added to a 0 °C mixture of tetrabutylammonium *tert*-butyl 4-(5-((2*S*,5*R*)-7-oxo-6-(sulfooxy)-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)piperazine-1-carboxylate (21 mg, 0.03mmol) in dry DCM (0.80 mL). The reaction mixture was stirred at 0 °C for 2-3 hrs then diluted with ether (~15 mL). The precipitate was collected via centrifugation, washed with ether (3x) and dried under high vacuum to afford (2*S*,5*R*)-7-oxo-2-(5-(piperazin-1-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (4 mg, 35%) as a light yellow solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI⁺, *m/z*): 375.2. ^{1}H NMR (300 MHz, D_2O) δ 4.65 (d, *J* = 6.6 Hz, 1H), 4.19 (br s, 1H), 3.80-3.65 (m, 2H), 3.38-3.28 (m, 2H), 3.20-3.16 (m, 1H), 2.99-2.95 (m, 1H), 2.32-1.88 (m, 4H).

***Example 16**: Synthesis of (2S,5R)-2-(5-amino-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 707**)*



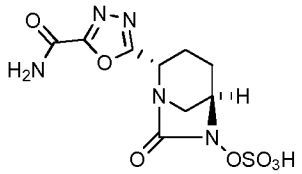
Step 1: Saturated $NaHCO_3$ (7.0 mL, 6.26 mmol) was added to a solution of (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbohydrazide TFA salt (2.3 g, 5.69 mmol) in dioxane (11.4 mL) and the reaction mixture was stirred at rt for 5 minutes. Cyanic bromide (3 M solution, 2.3 mL, 6.90 mmol) was added and the reaction mixture was stirred at

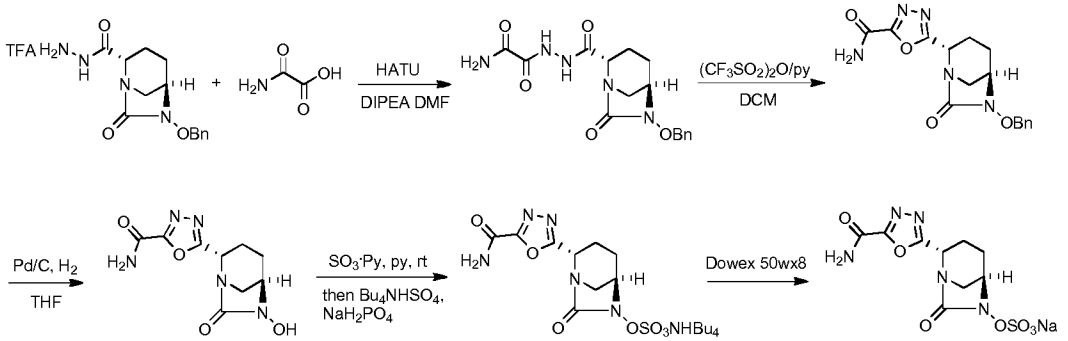
rt for 30 minutes. The reaction mixture was then loaded on a silica gel cartridge and purified by silica gel column chromatography (gradient elution 0-10% MeOH/DCM) to give (2*S*,5*R*)-2-(5-amino-1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diazabicyclo[3.2.1]octan-7-one (0.57 g, 32%). ESI-MS (EI^+, *m/z*): 316.4 $[M+H]^+$.

Step 2: *N*,*N*-Dimethylpyridin-4-amine (155 mg, 1.27 mmol) was added to a 0 °C solution of (2*S*,5*R*)-2-(5-amino-1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diazabicyclo[3.2.1]octan-7-one (0.20 g, 0.63 mmol), Boc_2O (0.27 g, 1.27 mmol), and triethylamine (0.18 mL, 1.27 mmol) in DMF. The reaction mixture was allowed to warm to rt and was stirred for 2-3 hrs. The reaction mixture was then concentrated, re-dissolved in DCM (50 mL), washed with water (50 mL), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (gradient elution 0-50% EtOAc/hexane) to give *tert*-butyl (5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)carbamate (0.16 g, 60.7%). ESI-MS (EI^+, *m/z*): 416.4 $[M+H]^+$.

Step 3-5: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate in Step 3 with *tert*-butyl (5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)carbamate, (2*S*,5*R*)-2-(5-amino-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate was obtained (64 mg) after prep-HPLC using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 306.25 $[M+H]^+$. ^1H NMR (300 MHz, D_2O) δ 4.61 (d, *J* = 6.6 Hz, 1H), 4.19 (br s, 1H), 3.17 (br d, *J* = 12.2 Hz, 1H), 2.98 (d, *J* = 12.3 Hz, 1H), 2.27-1.81 (m, 4H).

***Example 17**: Synthesis of (2S, 5R)-2-(5-carbamoyl-1,3,4-oxadiazol-2-yl)-7-oxo-1, 6-diazabicyclo[3. 2. 1]octan-6-yl hydrogen sulfate (**Compound 706**)*





Step 1: HATU (0.95 g, 2.5 mmol) was added to a 0 °C solution of (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbohydrazide (1.00 g, 2.5 mmol), 2-amino-2-oxoacetic acid (0.18 g, 2.1 mmol) and DIPEA (1.08 g, 8.4 mmol) in DMF (10 mL). The reaction mixture was stirred at 0 °C for 1 h then quenched with saturated sodium chloride (50 mL) and the organic layer was separated. The aqueous layer was exacted with EtOAc (3x). The combined organic layer was washed with saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (1:1 EtOAc/hexane) to give 2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoacetamide (0.57 g, 64%). ESI-MS (EI^+, *m/z*): 362 $[M+H]^+$.

Step 2: $(CF_3SO_2)_2O$ (0.58 g, 2.08 mmol) was slowly added to a -10 ^{0}C solution of 2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoacetamide (0.30 g, 0.83 mmol) and pyridine (0.6 mL) in dry DCM (5 mL). The reaction mixture was allowed to warm to rt. The reaction mixture was stirred at rt for 1 h then quenched with sat. $NaHCO_3$ very slowly. The organic layer was separated and the aqueous layer was exacted with EtOAc (3x). The combined organic layer was dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (gradient elution 1:10 to 2:1 EtOAc/hexane followed by 10:1 to 2:1 petroleum ether/EtOAC) to give 5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazole-2-carboxamide (0.18 g, 47%) as a slight yellow solid. ESI-MS (EI^+, *m/z*): 344.0 $[M+H]^+$.

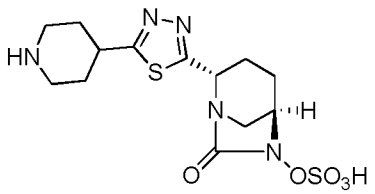
Step 3: To a solution of 5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazole-2-carboxamide (0.14 g, 0.41 mmol) in THF (10 mL) was added 10% Pd/C (0.14 g). The mixture was stirred under H_2 atmosphere at rt for 3 hrs then filtered and concentrated to provide 5-((2*S*,5*R*)-6-hydroxy-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-

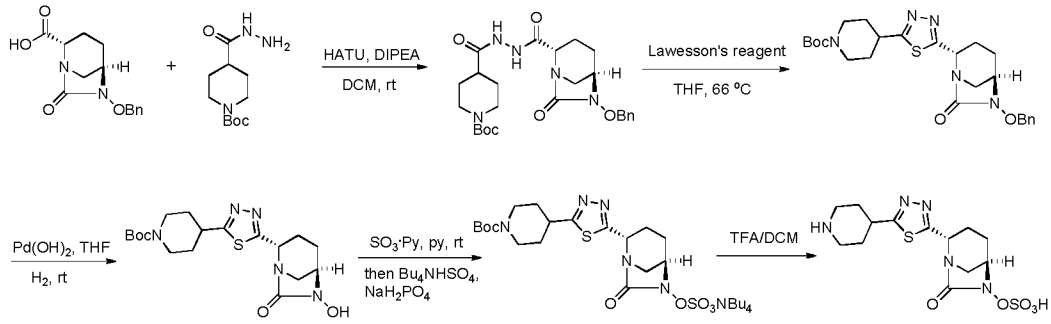
1,3,4-oxadiazole-2-carboxamide (103 mg, 100 %), which was directly used in the next step. ESI-MS (EI$^+$, *m/z*): 254 $[M+H]^+$.

Step 4: To a solution of 5-((2*S*,5*R*)-6-hydroxy-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazole-2-carboxamide (103 mg, 0.41 mmol) in dry pyridine (2.0 mL) was added SO_3·Py (323 mg, 2.03 mmol). The mixture was stirred at rt for 3 hrs and then concentrated under vacuum. The residue was re-dissolved in aqueous NaH_2PO_4 (1.5 M, 10 mL) then tetrabutylammonium hydrogen sulphate (166 mg, 0.49 mmol) was added. The mixture was stirred at rt for 20 minutes, then extracted with EtOAc (4x). The combined organic layer was dried and concentrated and the residue was purified by silica gel column chromatography (gradient elution 10:1 to 8:1 DCM/acetone) to afford tetrabutylammonium (2*S*,5*R*)-2-(1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate(110 mg, 36%). ESI-MS (EI$^-$, *m/z*): 333.0 $[M-H]^-$.

Step 5 Sodium Resin Exchange: tetrabutylammonium (2*S*,5*R*)-2-(1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate (110 mg) was dissolved in a minimum amount of HPLC grade water (~ 80 mL) and passed through a column of 20 g of DOWEX 50WX 8 Na^+ resin (the resin was pre-washed with >5L of HPLC grade water) and eluted with HPLC grade water to provide sodium (2*S*,5*R*)-2-(1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate (55 mg, 80%) as a white solid after lyophilization. ESI-MS (EI$^-$, *m/z*): 332.0 $[M-H]^-$. ^{1}H NMR (500 MHz, D_2O): δ 4.97-4.93 (m, 1H), 4.27 (br s, 1H), 3.29 (d, J = 11.0 Hz, 1H), 3.04 (d, J = 12.0 Hz, 1H), 2.43-2.39 (m, 1H), 2.31-2.23 (m, 2H), 2.04-1.98 (m, 1H).

***Example 18**: Synthesis of (2S,5R)-7-oxo-2-(5-(piperidin-4-yl)-1,3,4-thiadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 719**)*





Step 1: HATU (3.3 g, 8.7 mmol) and *tert*-butyl 4-(hydrazinecarbonyl)piperidine-1-carboxylate (2.29 g, 9.42 mmol) were added to a 0 °C solution of (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carboxylic acid (2 g, 7.25 mmol) in CH_2Cl_2 (50 mL), followed by the addition of DIPEA (2.8 g, 21.8 mmol). The reaction mixture was stirred at 0 °C for 12 hrs then washed with water and saturated sodium chloride, dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (gradient elution 1%-10% MeOH/CH_2Cl_2) to give *tert*-butyl 4-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinecarbonyl)piperidine-1-carboxylate as a white solid. (2.2 g, 62%). ESI-MS (EI^+, *m/z*): 502.2 $[M+H]^+$.

Step 2: Lawesson's reagent (0.16 g, 6 mol) was added to a solution of *tert*-butyl 4-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinecarbonyl)piperidine-1-carboxylate (0.16 g, 0.319 mmol) in THF (20 mL). The reaction mixture was stirred at 70 °C for 0.5 h. The solution was cooled to room temperature and sat. $NaHCO_3$ was added. The organic layer was separated and the aqueous layer was exacted with EtOAc (2x). The combined organic layer was dried over Na_2SO_4 and concentrated. The residue was purified by silica gel column chromatography (gradient elution 20%-50% EtOAc/petroleum ether) to give *tert*-butyl 4-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-thiadiazol-2-yl)piperidine-1-carboxylate (90 mg, 50%) as a white solid. ESI-MS (EI^+, *m/z*): 500.2 $[M+H]^+$. ^1H NMR (500 MHz, DMSO-d_6): δ 7.48-7.37 (m, 5H), 4.99-4.94 (m, 2H), 4.77 (d, J = 7.0 Hz, 1H), 3.99 (d, J = 11 Hz, 2H), 3.69 (s, 1H), 3.39-3.35 (m, 1H), 2.88-2.85 (m, 3H), 2.68 (d, J = 12 Hz, 1H), 2.44 (dd, J = 7.5, 5.5 Hz, 1H), 2.05-1.96 (m, 4H), 1.79-1.77 (m, 1H), 1.62-1.55 (m, 2H), 1.40 (s, 9H).

Step 3: To a solution of *tert*-butyl 4-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-thiadiazol-2-yl)piperidine-1-carboxylate (120 mg, 0.24 mmol)

in THF (30 mL) was added 10% $Pd(OH)_2/C$ (200 mg). The mixture was stirred under H_2 atmosphere at rt for 3 h, filtered and concentrated to afford *tert*-butyl 4-(5-((2*S*,5*R*)-6-hydroxy-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-thiadiazol-2-yl)piperidine-1-carboxylate as a yellow solid, which was directly used in the next step. ESI-MS (EI^+, *m/z*): 410.2 $[M+H]^+$.

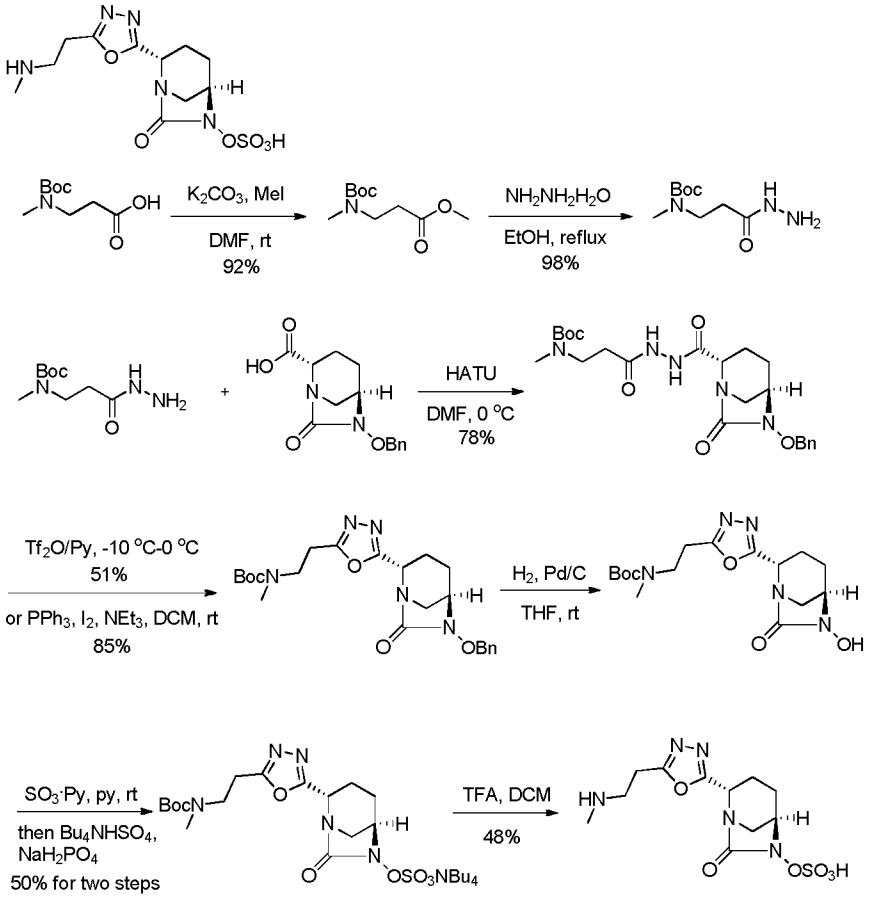
Step 4: To a solution of *tert*-butyl 4-(5-((2*S*,5*R*)-6-hydroxy-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-thiadiazol-2-yl)piperidine-1-carboxylate from the former step in dry pyridine (3 mL) was added $SO_3 \cdot Py$ (266 mg, 1.1 mmol). The mixture was stirred at rt for 3 hrs and then concentrated under vacuum. The residue was re-dissolved in aqueous NaH_2PO_4 (1.5 M, 20 mL) then tetrabutylammonium hydrogensulphate (150 mg, 0.44 mmol) was added. The mixture was stirred at rt for 20 minutes, then extracted with EtOAc (4x). The combined organic layer was dried and concentrated and the residue was purified by silica gel column chromatography (gradient elution 10:1 to 1:1 DCM/acetone) to afford tetrabutylammonium *tert*-butyl 4-(5-((2*S*,5*R*)-7-oxo-6-(sulfooxy)-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-thiadiazol-2-yl)piperidine-1-carboxylate as a white solid (110 mg, 62%). ESI-MS (EI^-, *m/z*): 488.1 $[M-H]^-$.

Step 5: Tetrabutylammonium *tert*-butyl 4-(5-((2*S*,5*R*)-7-oxo-6-(sulfooxy)-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-thiadiazol-2-yl)piperidine-1-carboxylate (110 mg, 0.15 mmol) was dissolved in a minimum amount of HPLC grade water (~ 15 mL) and passed through a column of 16 g of DOWEX 50WX 8 Na^+ resin (the resin was pre-washed with >0.5 L of HPLC grade water) and eluted with HPLC grade water to afford sodium (2*S*,5*R*)-2-(5-(1-(tert-butoxycarbonyl)piperidin-4-yl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-6-yl sulfate after lyophilization as a white solid (50 mg, 65%). ESI-MS (EI^-, *m/z*): 488.0 $[M-H]^-$. ^1H NMR (500 MHz, D_2O) δ 4.88 (d, *J* =7.0 Hz, 1H), 4.15 (s, 1H), 4.06 (d, *J* =10.5 Hz, 2H), 3.39-3.35 (m, 1H), 3.13 (d, *J* =2 Hz, 1H), 2.94-2.87 (m, 3H), 2.45-2.41 (m, 1H), 2.17-2.04 (m, 4H), 1.89-1.86 (m, 1H), 1.67-1.62 (m, 2H), 1.36 (s, 9H).

Step 6: TFA (0.20 mL) was added to a 0 °C mixture of sodium (2*S*,5*R*)-2-(5-(1-(tert-butoxycarbonyl)piperidin-4-yl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-6-yl sulfate (50 mg, 0.10 mmol) in dry DCM (0.60 mL). The reaction mixture was stirred at 0 °C for 2-3 hrs and then diluted with ether (~10 mL). The precipitate was collected via

centrifugation, washed with ether (3x) and dried under high vacuum to afford (2*S*,5*R*)-7-oxo-2-(5-(piperidin-4-yl)-1,3,4-thiadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (10 mg, 25%) after prep-HPLC using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 390.12.

***Example 19**: Synthesis of (2S,5R)-2-(5-(2-(methylamino)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 722)**



Step 1: Synthesis of methyl 3-(tert-butoxycarbonyl (methyl) amino)propanoate:

To a solution of 3-(*tert*-butoxycarbonyl(methyl)amino)propanoic acid (7.0 g, 0.032 mol) and K_2CO_3 (13.3 g, 0.096 mol) in DMF (100 mL) was added MeI (9.0 g, 0.064 mol) at rt. The resultant solution was stirred at rt for 3 hrs. The reaction mixture was quenched with ice water and extracted with ethyl acetate (2x). The combined organic layer was dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by silica gel column chromatography (gradient elution 0%~10% EtOAc/petroleum ether) to afford methyl 3-(*tert*-butoxycarbonyl (methyl) amino)propanoate (6.9 g, 92%) as a white solid. ESI-MS

(EI$^+$, *m/z*): 118 [M-100+H]$^+$.

Step 2: Synthesis of tert-butyl 3-hydrazinyl-3-oxopropyl (methyl) carbamate:

To a solution of methyl 3-(*tert*-butoxycarbonyl (methyl) amino)propanoate (6.9 g, 0.0317 mol) in EtOH (15 mL) was added hydrazine monohydrate (7.7 mL, 0.158 mol) at rt. The reaction mixture was heated to 80 °C and stirred at 80 °C overnight. The reaction mixture was concentrated, and then DCM (300 mL) was added. The organic layer was washed with water and saturated sodium chloride, dried over Na_2SO_4, and concenreated to afford *tert*-butyl 3-hydrazinyl-3-oxopropyl(methyl)carbamate (6.8 g, 98%) as sticky oil, which was used directly in the next step. ESI-MS (EI$^+$, *m/z*): 118 [M-100+H]$^+$.

Step 3: Synthesis of tert-butyl 3-(2-((2S, 5R)-6-(benzyloxy)-7-oxo-1, 6-diaza-bicyclo [3.2.1]octane-2-carbonyl)hydrazinyl)-3-oxopropyl(methyl)carbamate:

To a 0 °C solution of *tert*-butyl 3-hydrazinyl-3-oxopropyl(methyl)carbamate (4.3 g, 19.8 mmol) and (2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carboxylic acid (4.9 g, 0.0178 mol) in DMF (100 mL) was added HATU (8.2 g, 0.0218mol), followed by dropwise addition of DIPEA (9.6 mL, 0.0594 mol) slowly. The mixture was stirred at 0 °C for 1 h, and then quenched with ice water. The aqueous layer was extracted with EtOAc (2x). The combined organic layer was dried over Na_2SO_4, filtered and concentrated. The residue was purified by silica gel column chromatography (gradient elution 20~60% EtOAc/petroleum ether) to afford *tert*-butyl 3-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-3-oxopropyl(methyl)carbamate (6.7 g, 78%) as a white solid. ESI-MS (EI$^+$, *m/z*): 476 [M+H]$^+$.

Step 4: Synthesis of tert-butyl 2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl(methyl)carbamate:

Method A:

Tf_2O (7.2 mL, 0.0423 mol) was added slowly, drop-wise to a -78 °C solution of *tert*-butyl 3-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-3-oxopropyl(methyl)carbamate (6.7 g, 14.1 mmol) and pyridine (9.1 mL, 0.113 mol) in dry DCM (110 mL). The reaction mixture was allowed to warm to 0 °C then was stirred at 0 °C for 3 hrs. Aqueous $NaHCO_3$ was added at 0 °C very slowly. The organic layer was separated and the water layer was washed with DCM (3x). The combined organic layer was dried over

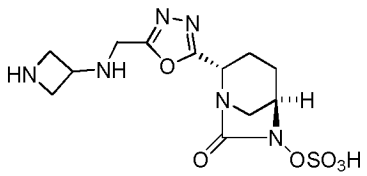
Na_2SO_4, and concentrated. The crude product was purified by reverse-phase biotage (water/acetonitrile gradient) to afford *tert*-butyl 2-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl(methyl)carbamate (3.3 g, 51%) as a light yellow solid. ESI-MS (EI^+, *m/z*): 458.0 $[M+H]^+$; ^1H NMR (500 MHz, $CDCl_3$): δ 7.45-7.36 (m, 5H), 5.09 (d, *J* = 11.5 Hz, 1H), 4.94 (d, *J* = 11.5 Hz, 1H), 4.71 (t, *J* = 4.5 Hz, 1H),3.67-3.59 (m, 2H), 3.37 (s, 1H), 3.31 (t, *J* = 6.5 Hz, 2H), 2.94-2.86 (m, 2H), 2.82 (s, 3H), 2.32-2.28 (m, 2H), 2.15-2.12 (m, 1H), 2.00-1.95 (m, 1H), 1.45 (s, 9H).

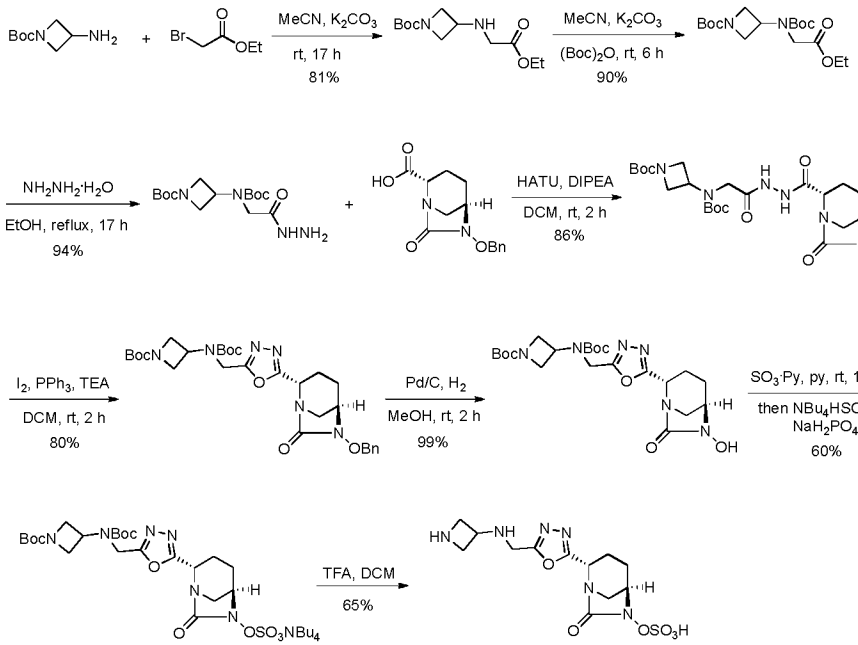
Method B:

To a solution of PPh_3 (5.3 g, 20.0 mmol) in CH_2Cl_2 (250 mL) at rt was added I_2 (5.2 g, 20.0 mmol). After I_2 was dissolved completely, the solution was cooled to 0 °C and TEA (7.0 mL, 50.0 mmol) was added.*Tert*-butyl3-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl) hydrazinyl)-3-oxopropyl(methyl)carbamate (4.8 g, 10.0 mol) was added and the mixture was stirred at rt for 1 hr. The mixture was concentrated, EtOAc(250 mL) was added, and the solution was filtered to remove $POPh_3$. The filtrate was concentrated and the residue was purified by silica gel column chromatography (gradient elution 30 to 50% EtOAc/petroleum ether) to afford *tert*-butyl 2-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl(methyl)carbamate (4.1 g, 85%) as a white solid. ESI-MS (EI^+, *m/z*): 458 $[M+H]^+$.

Step 5-7: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate in Step 3 with *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)(methyl)carbamate; (2S,5R)-2-(5-(2-(methylamino)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (1.2 g) was obtained as a white solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 348.2. ^1H NMR (300 MHz, D_2O) δ 4.76 (d, *J* = 6.3 Hz, 1H), 4.18 (br s, 1H), 3.44 (t, *J* = 7.1 Hz, 2H), 3.32 (t, *J* = 6.6 Hz, 2H), 3.18 (br d, *J* = 12.0 Hz, 1H), 2.93 (d, *J* = 12.3 Hz, 1H), 2.68 (s, 3H), 2.33 – 2.06 (m, 3H), 1.98 - 1.86 (m, 1H).

Example 20: *Synthesis of (2S,5R)-2-(5-((azetidin-3-ylamino)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 726**)*





Step 1: Synthesis of tert-butyl 3-(2-ethoxy-2-oxoethylamino)azetidine-1-carboxylate:

A mixture of *tert*-butyl 3-aminoazetidine-1-carboxylate (10.0 g, 58 mmol), ethyl 2-bromoacetate (10.7 g, 64 mmol) and potassium carbonate (24.0 g, 174 mmol) in MeCN (200 mL) was stirred at rt for 13 hrs. The reaction mixture was filtered and concentrated. The crude material was purified by silica gel column chromatography (gradient elution 0~66% EtOAc/petroleum ether) to afford *tert*-butyl 3-(2-ethoxy-2-oxoethylamino)azetidine-1-carboxylate (12.1 g, 81%) as a white solid. ESI-MS (EI^+, m/z): 259.0 $[M+H]^+$.

Step 2: Synthesis of tert-butyl 3-(tert-butoxycarbonyl(2-ethoxy-2-oxoethyl)amino)azetidine-1-carboxylate:

A mixture of *tert*-butyl 3-(2-ethoxy-2-oxoethylamino)azetidine-1-carboxylate (10.3 g, 40 mmol), di-*tert*-butyl dicarbonate (10.4 g, 48 mmol) and potassium carbonate (16.6 g, 120 mmol) in MeCN (200 mL) was stirred at rt for 6 hrs. The reaction mixture wasthen filtered and concentrated. The crude product was purified by silica gel column chromatography (gradient elution 0~80% EtOAc/petroleum ether) to afford *tert*-butyl 3-(*tert*-

butoxycarbonyl(2-ethoxy-2-oxoethyl)amino)azetidine-1-carboxylate (13.0 g, 90%) as a white solid. ESI-MS (EI^+, m/z): 359.0 $[M+H]^+$.

Step 3: Synthesis of tert-butyl 3-(tert-butoxycarbonyl(2-hydrazinyl-2-oxoethyl)amino)azetidine-1-carboxylate:

A mixture of *tert*-butyl 3-(*tert*-butoxycarbonyl(2-ethoxy-2-oxoethyl)amino)azetidine-1-carboxylate (7.2 g, 20 mmol), hydrazine (5.0 g, 100 mmol) and ethanol (50 mL) was stirred at 80 °C for 17 hrs. The reaction mixture was then concentrated to afford the crude *tert*-butyl 3-(*tert*-butoxycarbonyl(2-hydrazinyl-2-oxoethyl)amino)azetidine-1-carboxylate (6.4 g, 94%) as a white solid, which was used directly in the next step. ESI-MS (EI^+, m/z): 345.0 $[M+H]^+$.

Step 4: Synthesis of tert-butyl 3-((2-(2-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)(tert-butoxycarbonyl)amino)azetidine-1-carboxylate:

DIPEA (14 g, 0.11 mol) was added to a 0 °C solution of *tert*-butyl 3-(*tert*-butoxycarbonyl(2-hydrazinyl-2-oxoethyl)amino)azetidine-1-carboxylate (15 g, 0.044 mol), (5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carboxylic acid (10 g, 0.036 mol) and HATU (15 g, 0.04 mol) in CH_2Cl_2 (250 mL) . The mixture was allowed to warm to rt then was stirred at rt for 2 hrs. The mixture was quenched with saturated sodium chloride (50 mL) and the organic layer was separated. The water layer was extracted with EtOAc (3x). The combined organic layer was washed with saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (gradient elution 0~50% EtOAc/petroleum ether) to afford *tert*-butyl 3-((2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)(*tert*-butoxycarbonyl)amino)azetidine-1-carboxylate (18.5 g, 86%). ESI-MS (EI^+, *m/z*): 603.3 $[M+H]^+$.

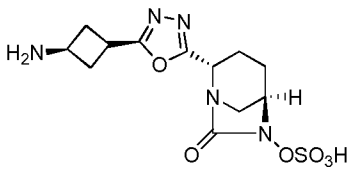
Step 5: Synthesis of tert-butyl 3-(((5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)(tert-butoxycarbonyl)amino)azetidine-1-carboxylate:

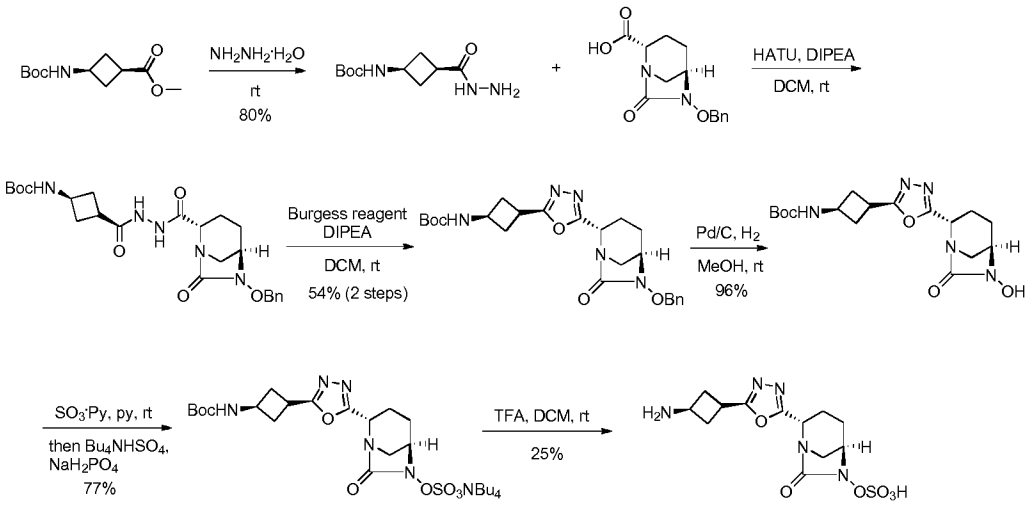
Et_3N (8.3 g, 0.082 mol) was added to a 0 °C solution of I_2 (10.43 g, 0.041 mol) and PPh_3 (10.76 g, 0.041 mol) in CH_2Cl_2 (250 mL). After the mixture was stirred at rt for 0.5 hr, *tert*-butyl 3-((2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)(*tert*-butoxycarbonyl)amino)azetidine-1-carboxylate (12.34

g, 0.0205 mol) was added. The mixture was stirred for another 1 hr. The mixture was then concentrated and EtOAc (250 mL) was added to the resulting residue. The residue, was stirred and then filtrated to remove Ph_3PO. The filtrate was concentrated and purified by silica gel column chromatography (gradient elution 33~50% EtOAc/petroleum ether) to afford *tert*-butyl 3-(((5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)(*tert*-butoxycarbonyl)amino) azetidine-1-carboxylate (9.6 g, 80%). ESI-MS (EI^+, *m/z*): 585.3 $[M+H]^+$.

Step 6-8: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate in Step 3 with *tert*-butyl 3-(((5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)(tert-butoxycarbonyl)amino)azetidine-1-carboxylate; (2S,5R)-2-(5-((azetidin-3-ylamino)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (1.5 g) was obtained as a white solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 375.1. ^1H NMR (300 MHz, D_2O) δ 5.00 (d, *J* = 5.4 Hz, 1H), 4.39 - 4.34 (m, 3H), 4.25 (s, 2H), 4.21 – 4.08 (m, 3H), 3.41 (br d, *J* = 13.1 Hz, 1H), 3.11 (d, *J* = 12.3 Hz, 1H), 2.57 – 2.28 (m, 3H), 2.19 - 2.08 (m, 1H).

***Example 21**: Synthesis of (2S,5R)-2-(5-((1r,3S)-3-aminocyclobutyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 727**)*





Step 1: Synthesis of tert-butyl ((1s,3s)-3-(hydrazinecarbonyl)cyclobutyl)carbamate:

A solution of (1s,3s)-methyl 3-((*tert*-butoxycarbonyl)amino)cyclobutanecarboxylate (1.0 g, 4.36 mmol) in $NH_2NH_2.H_2O$ (2 mL, 65.4 mmol) was stirred at rt for 12 hrs. Et_2O (20 mL) was then added to the mixture and the product was obtain by filtration. The solid material was dried under vacuum to give *tert*-butyl ((1s,3s)-3-(hydrazinecarbonyl)cyclobutyl)carbamate (0.8 g, 80%) as a white solid. ESI-MS (EI^+, *m/z*): 230.4.

Step 2: Synthesis of tert-butyl((1S,3r)-3-(2-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1] octane-2-carbonyl) hydrazinecarbonyl)cyclobutyl)carbamate:

HATU (56.4 g, 148 mmol), and DIPEA (27.8 mL, 160 mmol) were added to a solution of (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carboxylic acid (31.6 g, 114 mmol) and *tert*-butyl 4-hydrazinyl-4-oxobutylcarbamate (28.8 g, 126 mmol) in CH_2Cl_2 (460 mL). The mixture was stirred at rt for 4 hrs then diluted with CH_2Cl_2 (300 mL), washed with water (2x) and saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated to give a slightly yellow solid that was used in the next step without further purification. ESI-MS (EI^+, *m/z*): 488.5.

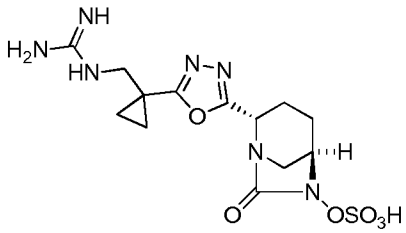
Step 3: Synthesis of tert-butyl((1S,3r)-3-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicycl[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)cyclobutyl)carbamate:

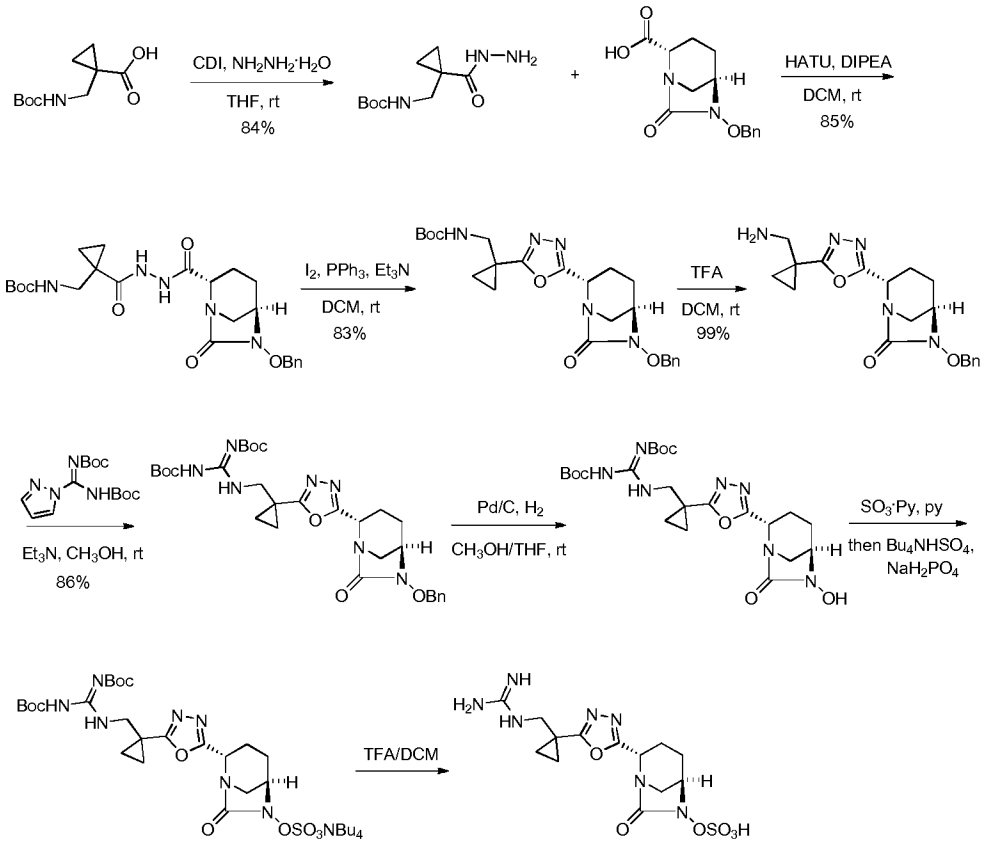
To a solution of *tert-butyl((1S,3r)-3-(2-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octane-2-carbonyl)hydrazinecarbonyl)cyclobutyl)carbamate* (65 g, 133

mmol) in DCM (445 mL) was added DIPEA (45 mL, 267 mmol), followed by and Burgess reagent (63.5 g, 267 mmol). The reaction mixture was stirred at rt 12 hrs and then diluted with CH_2Cl_2 (300 mL), washed with water (2x) and saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (gradient elution 0~50% DCM/acetone) to afford *tert-butyl((1S,3r)-3-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicycl[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)cyclobutyl)carbamate* as a slightly pink solid (29 g, 62 mmol, 54% over 2 steps). ESI-MS (EI^+, *m/z*): 470.5.

Step 4-6: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate in Step 3 with *tert*-butyl ((1S,3r)-3-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)cyclobutyl)carbamate; (2S,5R)-2-(5-((1r,3S)-3-aminocyclobutyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (3.3 g) was obtained as a white solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 360.2. ^1H NMR (300 MHz, D_2O) δ 4.74 (d, *J* = 7.6 Hz, 1H), 4.17 (br s, 1H), 3.96 – 3.80 (m, 1H), 3.72 – 3.55 (m, 1H), 3.17 (br d, *J* = 13.1 Hz, 1H), 2.90 (d, *J* = 12.3 Hz, 1H), 2.82-2.73 (m, 2H), 2.53-2.43 (m, 2H), 2.30-2.08 (m, 3H), 2.00 – 1.83 (m, 1H).

***Example 22**: Synthesis of (2S,5R)-2-(5-(1-(guanidinomethyl)cyclopropyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 723)**





Step 1: Synthesis of tert-butyl(1-(hydrazinecarbonyl)cyclopropyl)methylcarbamate: CDI (12.5 g, 0.077 mol) was added to a 0 °C solution of 1-((*tert*-butoxycarbonylamino)methyl)cyclopropanecarboxylic acid (15.0 g, 0.07 mol) in THF (250 mL). The mixture was allowed to warm to rt, and stirred at rt. for 2 hrs, and then $NH_2NH_2 \cdot H_2O$ (10.5 g, 0.21 mol) was added rapidly. The mixture was stirred for another 1 hr. The reaction mixture was concentrated, and then CH_2Cl_2 (500 mL) was added. The combined organic layer was washed with H_2O (100 mL), dried over Na_2SO_4, and concentrated to afford *tert*-butyl(1-(hydrazinecarbonyl)cyclopropyl)methylcarbamate (13.5 g, 84%). ESI-MS (EI^+, *m/z*): 230.2 $[M+H]^+$.

Step 2: Synthesis of tert-butyl(1-(2-((5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane- 2-carbonyl)hydrazinecarbonyl)cyclopropyl)methylcarbamate: DIPEA (14 g, 0.11 mol) was added to a solution of *tert*-butyl (1-(hydrazinecarbonyl)cyclopropyl)methylcarbamate (10.0 g, 0.044 mol), (5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carboxylic acid (10 g, 0.036 mol), and HATU (15 g, 0.04 mol) in CH_2Cl_2 (250 mL). The mixture was stirred at rt for 2 hrs. The mixture was diluted with CH_2Cl_2 (500 mL), washed with H_2O (300 mL), dried over Na_2SO_4, and

concentrated. The crude product was washed with EtOAc (200 mL), and filtrated to afford *tert*-butyl(1-(2-((5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinecarbonyl)cyclopropyl)methylcarbamate (15 g, 85%) as a white solid. ESI-MS (EI^+, *m/z*): 488.3 $[M+H]^+$.

Step 3: Synthesis of tert-butyl(1-(5-((5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2- yl)-1,3,4-oxadiazol-2-yl)cyclopropyl)methylcarbamate:

Et_3N (8.3 g, 0.082 mol) was added to a 0 °C solution of I_2 (10.43 g, 0.041 mol), PPh_3 (10.76 g, 0.041 mol) in CH_2Cl_2 (250 mL). The mixture was allowed to warm to rt. After stirring at rt for 0.5 hr, *tert*-butyl(1-(2-((5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza- bicyclo[3.2.1]octane-2-carbonyl)hydrazinecarbonyl)cyclopropyl)methylcarbamate (10 g, 0.0205 mol) was added. The mixture was stirred at rt for another 1 hr. The mixture was concentrated, EtOAc(250 mL) was added, and the mixture was filtered to remove Ph_3PO. The filtrate was concentrated and the residue was purified by silica gel column chromatography (gradient elution 33~50% EtOAc/petroleum ether) to afford *tert*-butyl (1-(5-((5*R*)-6- (benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)cyclopropyl)methylcarbamate (8 g, 83%) as a white solid. ESI-MS (EI^+, *m/z*): 470.3 $[M+H]^+$.

Step 4: Synthesis of (5R)-2-(5-(1-(aminomethyl)cyclopropyl)-1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one:

TFA (30 mL) was added to a 0 °C solution of *tert*-butyl(1-(5-((5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza- bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)cyclopropyl)methylcarbamate (8 g, 0.017 mol) in DCM (100 mL). The mixture was allowed to warm to rt and was stirred at rt for 1 h. The mixture was concentrated and the residue was washed with Et_2O (50 mL), and then filtrated to afford (5*R*)-2-(5-(1-(aminomethyl)cyclopropyl)- 1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one (7 g, 99%), which was used directly in the next step. ESI-MS (EI^+, *m/z*): 370.2 $[M+H]^+$.

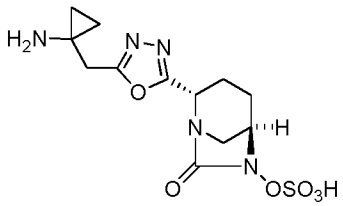
Step 5: Synthesis of (5R)-2-(5-(1-(2,3-bis-(tert-butoxycarbonyl)-guanidinomethyl)cyclopropyl)- 1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one:

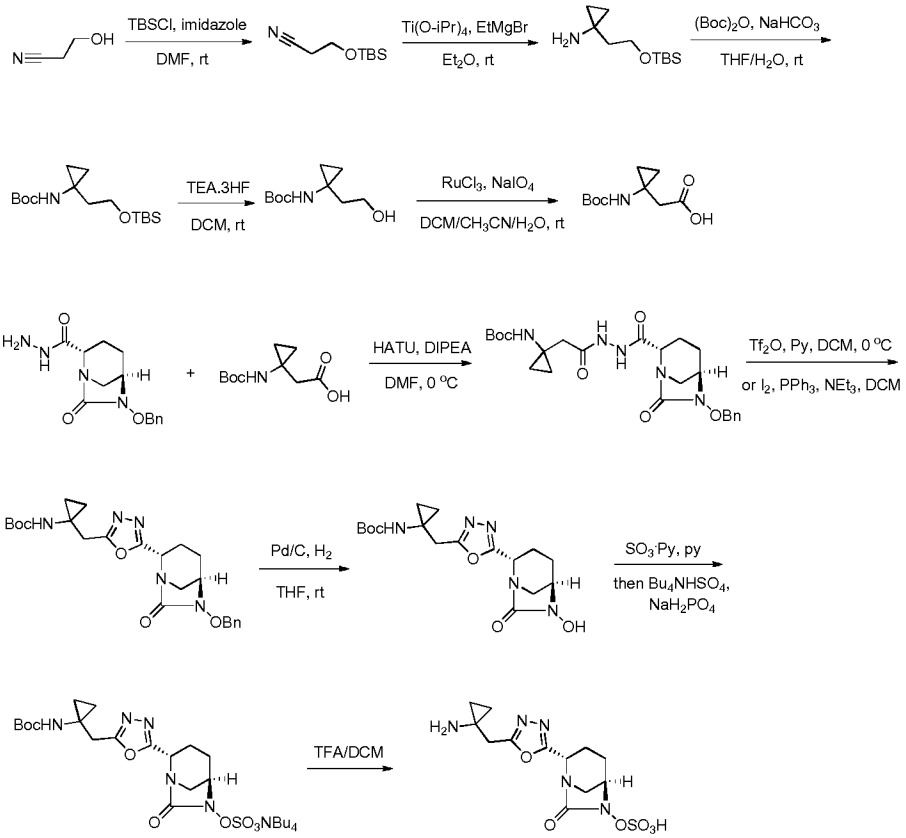
Et_3N (5 g, 0.05 mol) and tert-butyl (((tert-butoxycarbonyl)amino)(1H-pyrazol-1-yl)methylene)carbamate (5.5 g, 17.5 mmol) were added to a solution of (5*R*)-2-(5-(1-(aminomethyl)cyclopropyl)-1,3,4-oxadiazol-2-yl)- 6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one (7 g, 0.017 mol) in CH_3OH (500 mL) . The mixture was stirred at

rt for 4 hrs and then concentrated. The residue was purified by silica gel column chromatography (gradient elution 50 to 66% EtOAc/petroleum ether) to afford (5*R*)-2-(5-(1-(2,3-bis- (*tert*-butoxycarbonyl)-guanidinomethyl)cyclopropyl)-1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one (9 g, 86%) as a white solid. ESI-MS (EI^+, *m/z*): 612.3 $[M+H]^+$.

Step 6-8: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate in Step 3 with (5*R*)-2-(5-(1-(2,3-bis-(*tert*-butoxycarbonyl)-guanidinomethyl) cyclopropyl)-1,3,4-oxadiazol-2-yl)-6-(benzyloxy)-1,6-diaza-bicyclo[3.2.1]octan-7-one; (2S,5R)-2-(5-(1-(guanidinomethyl)cyclopropyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (0.74 g) was obtained as a white solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 402.1. ^1H NMR (300 MHz, D_2O) δ 4.74 (d, *J* = 7.9 Hz, 1H), 4.17 (s, 1H), 3.57 (s, 2H), 3.17 (br d, *J* = 12.9 Hz, 1H), 2.88 (d, *J* = 12.3 Hz, 1H), 2.32 – 2.05 (m, 3H), 1.98-1.82 (m, 1H), 1.38 (br s, 2H), 1.23 (br s, 2H).

***Example 23**: Synthesis of (2S,5R)-2-(5-((1-aminocyclopropyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 724**):*





Step 1: Synthesis of 3-(tert-butyldimethylsilyloxy)propanenitrile:

Imidazole (33.6 g, 495 mmol) and *tert*-butyldimethylsilyl chloride (27.2 g, 180 mmol) were added to a 0 °C solution of 3-hydroxypropanenitrile (10.6 g, 150 mmol) in DMF 50 mL). The mixture was allowed to warm to rt, then was stirred at rt for 12 hrs. The mixture was quenched with water (500 mL), and then extracted with EtOAc (3x). The combined organic layer was dried over Na_2SO_4 and concentrated. The residue was purified by silica gel column chromatography (gradient elution 0~5% EtOAc/petroleum ether) to give 3-(*tert*-butyldimethylsilyloxy) propanenitrile (18 g, 75%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.74 (t, J = 6.0 Hz, 2H), 2.43 (t, J = 6.0 Hz, 2H), 0.81 (s, 9H), 0.00 (s, 6H).

Step 2: Synthesis of 1-(2-(tert-butyldimethylsilyloxy)ethyl)cyclopropanamine:

To a solution of 3-(*tert*-butyldimethylsilyloxy)propanenitrile (11.1 g, 60 mmol) in Et_2O (400 mL) was added titanium tetraisopropanolate (28.9 g, 102 mmol) under N_2 atmosphere. Ethylmagnesium bromide (3M in Et_2O, 50 mL) was slowly added drop-wise at 0 °C. The mixture was stirred at rt for 1 hr. Boron trifluoride etherate (17.0 g, 120 mmol) was slowly added at 0 °C. The mixture was stirred at rt for 1 hr. The mixture was quenched with 10%

aq. NaOH (300 mL) and then extracted with DCM (3x). The combined organic layer was dried over Na_2SO_4 and concentrated. The residue was purified by silica gel column chromatography (gradient elution 5~50% EtOAc/petroleum ether) to afford 1-(2-(*tert*-butyldim ethylsilyloxy)ethyl)cyclopropanamine (3.9 g, 30%) as a colorless oil. ESI-MS (EI^+, *m/z*): 216.2 $[M+H]^+$.

Step 3: Synthesis of tert-butyl 1-(2-(tert-butyldimethylsilyloxy)ethyl)cyclopropyl-carbamate:
A solution of 1-(2-(*tert*-butyldimethylsilyloxy)ethyl)cyclopropanamine (1.9 g, 8.8 mmol), $(Boc)_2O$ (2.9 g, 13.2 mmol), $NaHCO_3$ (1.5 g, 17.6 mmol) in THF/H_2O (20 mL/20 mL) was stirred at rt for 17 hrs. The mixture was extracted with EtOAc (3x). The combined organic layer was dried over Na_2SO_4 and concentrated. The residue was purified by silica gel column chromatography (0~15% gradient elution EtOAc/petroleum ether) to afford *tert*-butyl 1-(2-(*tert*-butyldimethylsilyloxy)ethyl)cyclopropylcarbamate (2.5 g, 90%) as a colorless oil. ESI-MS (EI^+, *m/z*): 316 $[M+H]^+$.

Step 4: Synthesis of tert-butyl 1-(2-hydroxyethyl)cyclopropylcarbamate:
A solution of *tert*-butyl 1-(2-(*tert*-butyldimethylsilyloxy)ethyl)cyclopropylcarbamate (11.9 g, 37.8 mmol) and 3HF·TEA (22.0 g) in DCM (50 mL) was stirred at rt for 17 hrs. The mixture was concentrated and the residue was purified by silica gel column chromatography (0~20% gradient elution EtOAc/petroleum ether) to afford *tert*-butyl 1-(2-hydroxyethyl)cyclopropylcarbamate (4.6 g, 60%) as a white solid.

Step 5: Synthesis of 2-(1-(tert-butoxycarbonylamino)cyclopropyl)acetic acid:
$RuCl_3.H_2O$ (124 mg, 0.6 mmol) was added to a solution of *tert*-butyl 1-(2-hydroxyethyl)cyclopropylcarbamate (6.1 g, 30 mmol), and $NaIO_4$ (19.0 g, 90 mmol) in DCM/H_2O/CH_3CN (20 mL/40 mL/20 mL). The mixture was stirred at rt for 3 hrs. The mixture was then diluted with H_2O (100 mL), and extracted with DCM (3x). The combined organic layer was dried over Na_2SO_4 and concentrated. The residue was purified by silica gel column chromatography (0~30% gradient elution EtOAc/petroleum ether) to afford 2-(1-(*tert*-butoxycarbonylamino)cyclopropyl)acetic acid (6.0 g, 90%) as a white solid. ESI-MS (EI^+, *m/z*): 238 $[M+Na]^+$.

Step 6: Synthesis of tert-butyl 1-(2-(2-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)cyclopropylcarbamate:

A solution of 2-(1-(*tert*-butoxycarbonylamino)cyclopropyl)acetic acid (1.5 g, 6.9 mmol), (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbohydrazide (3.1 g, 7.6 mmol), DIPEA (2.7 g, 21.0 mmol), and HATU (3.9 g, 10.45 mmol) in DMF (20 mL) was stirred at 0 °C for 1 hr. The mixture was quenched with saturated sodium chloride (150 mL) and EtOAc (150 mL). The organic layer was separated and washed with saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (0~80% gradient elution EtOAc/petroleum ether) to afford *tert*-butyl 1-(2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)cyclopropylcarbamate (2.4 g, 70%) as a white solid. ESI-MS (EI^+, *m/z*): 488 $[M+H]^+$.

Step 7: Synthesis of tert-butyl 1-((5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)cyclopropylcarbamate:

Method A:

Pyridine (5.2 g, 65.6 mmol) was added to a 0 °C solution of *tert*-butyl 1-(2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)cyclopropylcarbamate (4.0 g, 8.2 mmol) in DCM (40 mL). Tf_2O (5.7 g, 20.5 mmol) was added slowly at 0 °C. The reaction mixture was stirred at 0 °C for 3.5 hrs. Sat. $NaHCO_3$ was added very slowly at 0 °C. The organic layer was separated and washed with saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (0~70% gradient elution EtOAc/petroleum ether) to afford *tert*-butyl 1-((5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)cyclopropylcarbamate (2.6 g, 65%) as a yellow solid. ESI-MS (EI^+, *m/z*): 470 $[M+H]^+$.

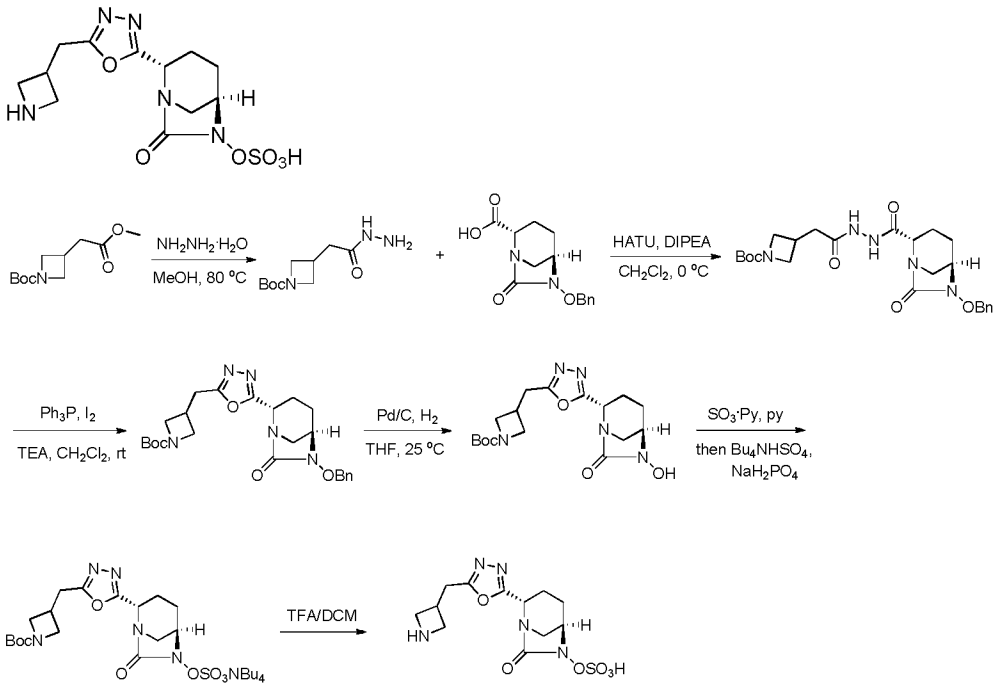
Method B:

To s solution of PPh_3 (5.2 g, 20.0 mmol) in dry DCM (60 mL) was added I_2 (5.1 g, 20.0 mmol). After I_2 was dissolved completely, TEA (7.0 mL, 50.0 mmol) was added quickly at rt. The mixture was stirred for 15 mins. *Tert*-butyl 1-(2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)cyclopropyl-carbamate (4.9 g, 10.0 mmol) was added and the mixture was stirred at rt for 1 hr. The solvent was concentrated. EtOAc (250 mL) was added, and the solution was filtered to remove PPh_3O.

The filtrate was concentrated and the residue was purified by silica gel column chromatography (0~60% gradient elution EtOAc/petroleum ether) to afford *tert*-butyl 1-((5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)cyclopropyl-carbamate (4.1 g, 87%) as a white solid. ESI-MS (EI^+, *m/z*): 470 $[M+H]^+$.

Step 8-10: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate in Step 3 with *tert*-butyl (1-((5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)cyclopropyl)carbamate; (2S,5R)-2-(5-((1-aminocyclopropyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (0.78 g) was obtained as a white solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 360.1. ^1H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 6.4 Hz, 1H), 4.16 (br s, 1H), 3.25 (s, 2H), 3.17 (br d, *J* = 12.7 Hz, 1H), 2.95 (d, *J* = 12.4 Hz, 1H), 2.34 – 2.03 (m, 3H), 2.00 – 1.82 (m, 1H), 1.08 – 0.86 (m, 4H).

***Example 24**: Synthesis of (2S,5R)-2-(5-(azetidin-3-ylmethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 725**)*



Step 1: Synthesis of tert-butyl 3-(2-hydrazinyl-2-oxoethyl)azetidine-1-carboxylate:

To a solution of t*ert*-butyl 3-(2-methoxy-2-oxoethyl)azetidine-1-carboxylate (25.0 g, 109 mmol) in MeOH (150 mL) was added $NH_2NH_2 \cdot H_2O$ (27.3 g, 546 mmol) at rt. The mixture was heated at 65 °C for 12 hrs and then concentrated. The residue was diluted with DCM (400 mL), washed with water (2x) and saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated to give *tert*-butyl 3-(2-hydrazinyl-2-oxoethyl)azetidine-1-carboxylate (24.0 g, 96%) as a yellow gum. ESI-MS (EI^+, *m/z*): 252 $[M+Na]^+$.

Step 2: Synthesis of tert-butyl 3-(2-(2-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)azetidine-1-carboxylate:

HATU (19.6 g, 52.2 mmol) and DIPEA (16.6 g, 130.5 mmol) were added to a 0 °C solution of (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carboxylic acid (12.0 g, 43.5 mmol), *tert*-butyl 3-(2-hydrazinyl-2-oxoethyl)azetidine-1-carboxylate(11.3 g, 49.8 mmol) in CH_2Cl_2 (360 mL). The mixture was allowed to warm to rt then the mixture was stirred at rt for 12 hrs. The mixture was then diluted with CH_2Cl_2 (300 mL), washed with water (2x)and saturated sodium chloride(2x), dried and concentrated. The residue was purified by silica gel column chromatography (0~20% gradient elution EtOAc/petroleum ether) to afford *tert*-butyl 3-(2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)azetidine-1-carboxylate (19.3 g, 93%) as a white solid. ESI-MS (EI^+, *m/z*): 488 $[M+H]^+$.

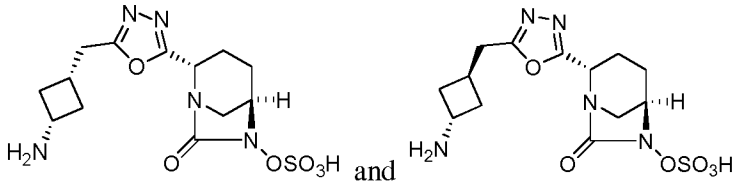
Step 3: Synthesis of tert-butyl 3-((5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)azetidine-1-carboxylate:

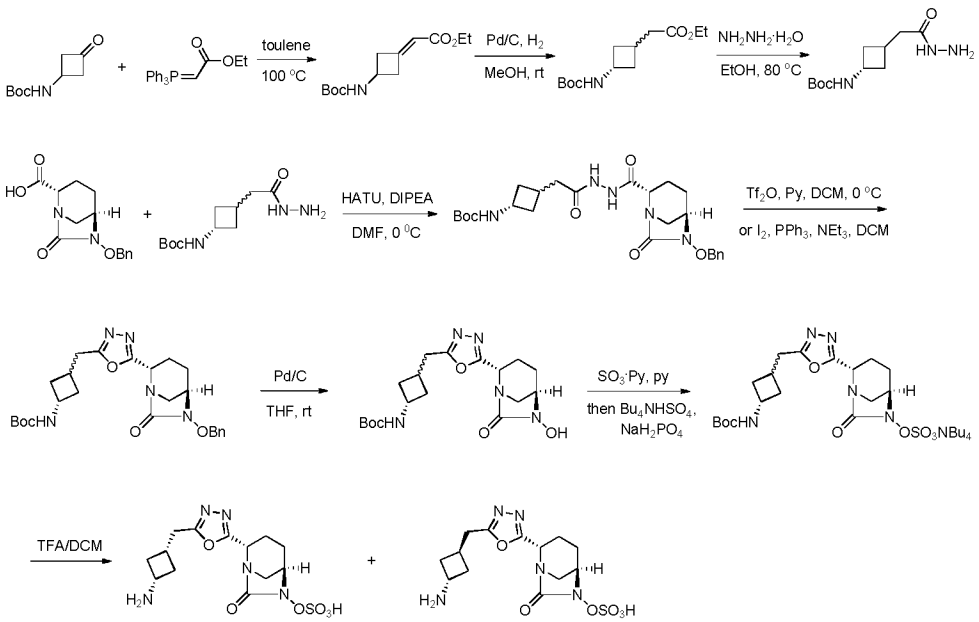
To s solution of PPh_3 (2.2 g, 8.2 mmol) in dry DCM (60 mL) was added I_2 (2.1 g, 8.2 mmol). After I_2 was dissolved completely, TEA (1.7 g, 16.4 mmol) was added quickly at rt. The mixture was stirred for 15 mins. *Tert*-butyl 3-(2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)azetidine-1-carboxylate (2.0 g, 4.1 mmol) was added. The mixture was stirred at rt for 1 h. The reaction mixture was concentrated and the residue was purified by silica gel column chromatography (gradient elution 0~40% EtOAc/petroleum ether) to afford *tert*-butyl 3-((5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)azetidine-1-carboxylate (1.3 g, 66%) as a white solid. ESI-MS (EI^+, *m/z*): 470 $[M+H]^+$.

Step 4-6: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate

in Step 3 with *tert*-butyl 3-((5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)azetidine-1-carboxylate, (2S,5R)-2-(5-(azetidin-3-ylmethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate was obtained as a white solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 360.2. ^1H NMR (300 MHz, D_2O) 4.74 (d, *J* = 6.4 Hz, 1H), δ 4.23 – 4.15 (m, 3H), 3.95 (dd, *J* = 11.5, 7.5 Hz, 2H), 3.50 – 3.30 (m, 1H), 3.25 (d, *J* = 6.0 Hz, 2H), 3.17 – 3.14 (m, 1H), 2.88 (d, *J* = 12.0 Hz, 1H), 2.27 – 2.05 (m, 3H), 1.95-1.85 (m, 1H).

Example 25**: Synthesis of (2S,5R)-2-(5-(((1s,3R)-3-aminocyclobutyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 728) and *(2S,5R)-2-(5-(((1r,3S)-3-aminocyclobutyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 751)***





Step 1: Synthesis of ethyl 2-(3-(tert-butoxycarbonylamino)cyclobutylidene) acetate:

To a solution of *tert*-butyl 3-oxocyclobutylcarbamate (1.0 g, 5.4 mmol) in toluene (10 mL) was added ethyl 2-(triphenylphosphoranylidene)acetate (2.1 g, 5.9 mmol). The reaction

mixture was heated at 100 °C for 2 hrs, and then concentrated. The residue was purified by silica gel column chromatography(10% EtOAc/petroleum ether) to afford ethyl 2-(3-(*tert*-butoxycarbonylamino)cyclobutylidene)acetate (1.2 g, 89%). ESI-MS (EI^+, *m/z*): 256 $[M+H]^+$.

Step 2: Synthesis of ethyl 2-(3-(tert-butoxycarbonylamino) cyclobutyl) acetate:
10% Pd/C (360 mg) was added to a solution of ethyl 2-(3-(*tert*-butoxycarbonylamino)cyclobutylidene) acetate (1.2 g, 4.8 mmol) in MeOH (10 mL) at 23 °C. The reaction mixture was stirred under a H_2 balloon at rt for 1.5 hrs. The mixture was filtered and concentrated. The residue was purified by silica gel column (10% EtOAc/petroleum ether) to afford ethyl 2-(3-(*tert*-butoxycarbonylamino)cyclobutyl)-acetate (1.2 g, 96%). ESI-MS (EI^+, *m/z*): 258 $[M+H]^+$.

Step 3: Synthesis of tert-butyl 3-(2-hydrazinyl-2-oxoethyl)cyclobutylcarbamate:
A solution of ethyl 2-(3-(*tert*-butoxycarbonylamino)cyclobutyl) acetate (1.2 g, 4.7 mmol) and hydrazine hydrate (1.4 g, 23.5 mmol) in EtOH (8 mL) was heated at 80 °C for 17 hrs. The reaction mixture was concentrated and the residue was dissolved in DCM (20 mL). The organic phase was washed with saturated sodium chloride (10 mL) and water (10 mL). The water layer was exacted with EtOAc (3x). The combined organic layer was dried over Na_2SO_4 and concentrated to afford *tert*-butyl 3-(2-hydrazinyl-2-oxoethyl) cyclobutylcarbamate (1.1 g, 97%). ESI-MS (EI^+, *m/z*): 244 $[M+H]^+$.

Step 4: Synthesis of tert-butyl 3-(2-(2-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo [3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl) cyclobutylcarbamate:
HATU (1.6 g, 4.3 mmol) and DIPEA (0.93 g, 7.2 mmol) were added to a 0 °C solution of (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1] octane-2-carboxylic acid (1.0 g, 3.6 mmol), *tert*-butyl 3-(2-hydrazinyl-2-oxoethyl) cyclobutylcarbamate (0.97 g, 3.9 mmol) in DMF (10 mL) at . The reaction mixture was stirred at 0 °C for 1 hr. The mixture was quenched with saturated sodium chloride (50 mL) and the organic layer was separated. The water layer was exacted with EtOAc (3x). The combined organic layer was washed with saturated sodium chloride (2x), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column chromatography (50% EtOAc/petroleum ether) to afford *tert*-butyl 3-(2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl) cyclobutylcarbamate (1.5 g, 88%). ESI-MS (EI^+, *m/z*): 502

$[M+H]^+$.

Step 5: Synthesis of tert-butyl 3-((5-((2*S*, 5*R*)-6-(benzyloxy)-7-oxo-1, 6-diaza-bicyclo [3.2.1] octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl) cyclobutylcarbamate:

Method A:

To a solution of *tert*-butyl 3-(2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl) cyclobutylcarbamate (1.0 g, 1.99 mmol) in DCM (20 mL) was added pyridine (1.5 mL). $(CF_3SO_2)_2O$ (1.4 g, 4.97 mmol) was added slowly at -10 °C. The reaction mixture was stirred at 0 °C for 1 h. Sat. $NaHCO_3$ was added at 0 °C very slowly. The organic layer was separated and the water layer was exacted with EtOAc (3x). The combined organic layer was dried over Na_2SO_4 and concentrated. The residue was purified by silica gel column chromatography (gradient elution10~50% EtOAc/petroleum ether) to afford *tert*-butyl 3-((5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl) cyclobutylcarbamate (0.7 g, 48%) as a slight yellow solid. ESI-MS (EI^+, *m/z*): 484.0 $[M+H]^+$.

Method B:

To s solution of PPh_3 (7.9 g, 30.0 mmol) in dry DCM (60 mL) was added I_2 (7.8 g, 30.0 mmol). After I_2 was dissolved completely, TEA (10.5 mL, 75.0 mmol) was added quickly at rt. The mixture was stirred for 15 mins. *Tert*-butyl 3-(2-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinyl)-2-oxoethyl)cyclobutyl-carbamate (4.9 g, 15.0 mmol) was added. The mixture was stirred at rt for 1 hr. The solvent was concentrated. EtOAc (300 mL) was added, and the solution was filtered to remove PPh_3O. The filtrate was concentrated. The residue was purified by silica gel column chromatography (gradient elution 0~50% EtOAc/petroleum ether) to afford *tert*-butyl 3-((5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl) cyclobutyl-carbamate (6.2 g, 85%) as a white solid. ESI-MS (EI^+, *m/z*): 484.0 $[M+H]^+$.

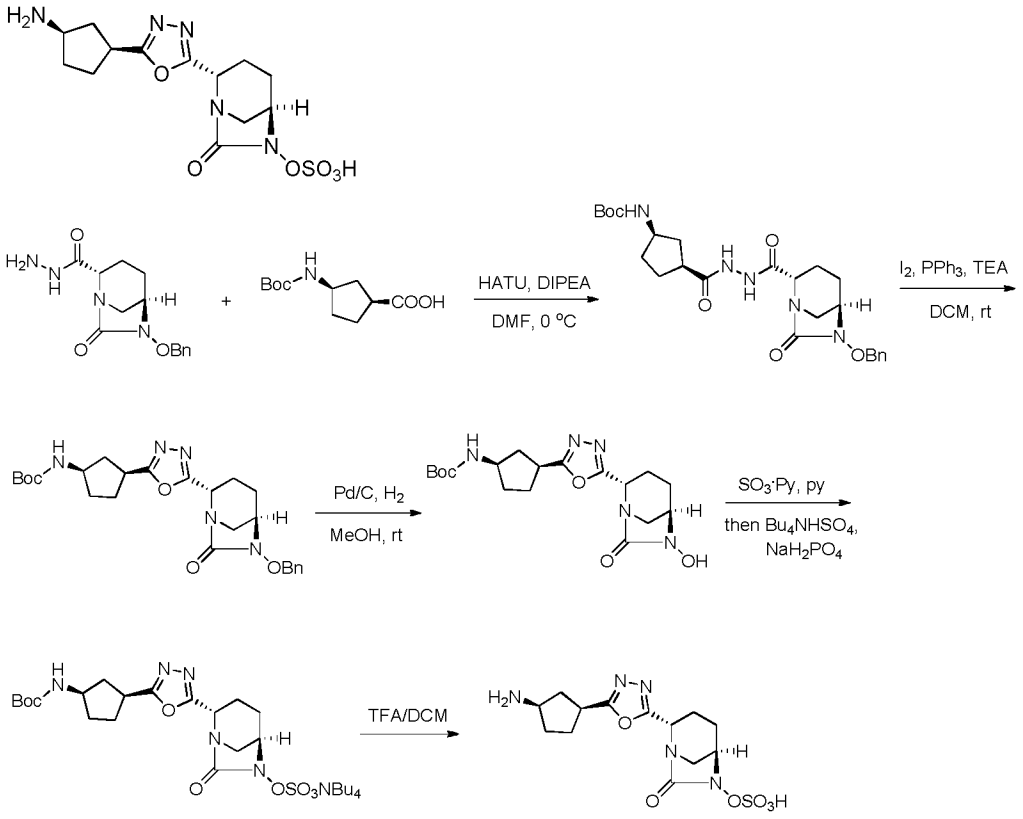
Step 6-8: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate in Step 3 with *tert*-butyl (3-((5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)methyl)cyclobutyl)carbamate, (2S,5R)-2-(5-(((1s,3R)-3-aminocyclobutyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl

hydrogen sulfate (245 mg) and (2S,5R)-2-(5-(((1r,3S)-3-aminocyclobutyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (178 mg) were obtained as white solids after prep-HPLC purification using ammonium formate buffer.

(2S,5R)-2-(5-(((1s,3R)-3-aminocyclobutyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 728**): ESI-MS (EI^+, *m/z*): 374.3. ^1H NMR (300 MHz, D_2O) δ 4.76 (d, *J* = 6.5 Hz, 1H), 4.15 (br s, 1H), 3.71 – 3.55 (m, 1H), 3.16 (br d, *J* = 11.5 Hz, 1H), 3.00 (d, *J* = 6.7 Hz, 2H), 2.86 (d, *J* = 12.3 Hz, 1H), 2.58-2.40 (m, 3H), 2.32 – 2.03 (m, 3H), 1.96-1.78 (m, 3H).

(2S,5R)-2-(5-(((1r,3S)-3-aminocyclobutyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 751**): ESI-MS (EI^+, *m/z*): 374.0. ^1H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 6.5 Hz, 1H), 4.15 (br s, 1H), 3.89-3.79 (m, 1H), 3.16 (br d, *J* = 12.0 Hz, 1H), 3.07 (d, *J* = 6.0 Hz, 2H), 2.87 (d, *J* = 8.0 Hz, 1H), 2.86-2.78 (m, 1H), 2.35 – 2.05 (m, 7H), 1.99 – 1.83 (m, 1H).

***Example 26**: Synthesis of (2S,5R)-2-(5-((1S,3R)-3-aminocyclopentyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 729**)**



Step 1: Synthesis of tert-butyl(1R,3S)-3-(2-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo [3.2.1]octane-2-carbonyl)hydrazinecarbonyl)cyclopentylcarbamate:

To a 0 °C solution of (1*S*,3*R*)-3-(*tert*-butoxycarbonylamino)cyclopentanecarboxylic acid (3.8 g, 16.6 mmol) and (2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbohydrazide (5.3 g, 18.26 mmol) in DMF (30 mL) were added HATU (7.6 g, 19.92 mmol) and DIPEA (11.6 ml, 66.4 mmol). The reaction mixture was stirred at 0 °C for 1.5 hrs. The reaction mixture was diluted with water and extracted with EtOAc (2x). The combined organic layer was washed with saturated sodium chloride (4x) and citric acid (5% aq.), dried over Na_2SO_4, and concentrated. The residue was purified by silica gel column (gradient elution 50~80% EtOAc/petroleum ether) to afford *tert*-butyl (1*R*,3*S*)-3-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl) hydrazinecarbonyl) cyclopentylcarbamate (4.5 g, 55%) as a white solid. ESI-MS (EI^+, *m/z*): 502.3 $[M+H]^+$.

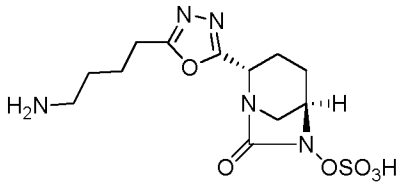
Step 2: Synthesis of tert-butyl(1R,3S)-3-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo [3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)cyclopentylcarbamate:

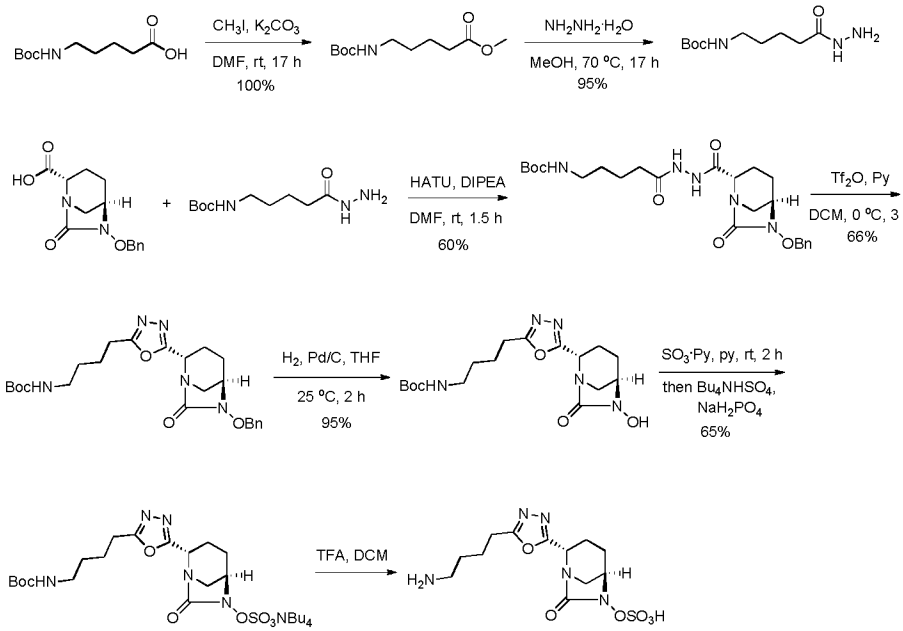
To a 0 °C solution of PPh_3 (2.2 g 8.4 mmol) in dry DCM (20 mL) was added I_2 (2.1 g, 8.4 mmol). After I_2 was dissolved, TEA (2.4 mL, 16.8 mmol) was added quickly at rt. The reaction mixture was stirred for 15 min. *tert*-Butyl (1*R*,3*S*)-3-(2-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octane-2-carbonyl)hydrazinecarbonyl) cyclopentylcarbamate (2.1 g, 4.2 mmol) was added. The reaction mixture was stirred at rt for 1 h. The reaction mixture was concentrated and the residue was purified by silica gel column (gradient elution 0~50% EtOAc/petroleum ether) to afford the crude *tert*-butyl (1*R*,3*S*)-3-(5-((2*S*,5*R*)-6-(benzyloxy)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl) cyclopentylcarbamate (~1.7 g) as a white solid. ESI-MS (EI^+, *m/z*): 484.1.

Step 3-5: Following Steps 3-5 in Example 4, replacing *tert*-butyl (2-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)ethyl)carbamate in Step 3 with *tert*-butyl ((1R,3S)-3-(5-((2S,5R)-6-(benzyloxy)-7-oxo-1,6-diazabicyclo[3.2.1]octan-2-yl)-1,3,4-oxadiazol-2-yl)cyclopentyl)carbamate; (2S,5R)-2-(5-((1S,3R)-3-aminocyclopentyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (286 mg) was obtained as a white solid after prep-HPLC purification using ammonium formate buffer. ESI-MS (EI^+, *m/z*): 374.2. ^1H NMR (300 MHz, D_2O) δ 4.74 (d, *J* = 6.5 Hz, 1H), 4.16 (br s, 1H), 3.82 – 3.66 (m, 1H), 3.56 – 3.41 (m, 1H), 3.15 (br d, *J* = 12.3 Hz, 1H), 2.89 (d, *J* = 12.3 Hz, 1H), 2.67 – 2.51 (m, 1H), 2.30 – 1.69 (m, 9H).

The compounds described in Examples 27-87 were prepared as described in the reaction schemes following similar procedures of Examples 1-26.

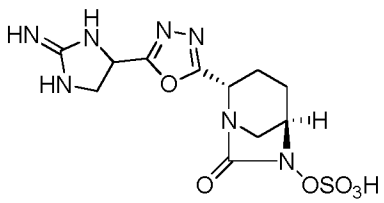
***Example 27**: Synthesis of (2S,5R)-2-(5-(4-aminobutyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 735)**

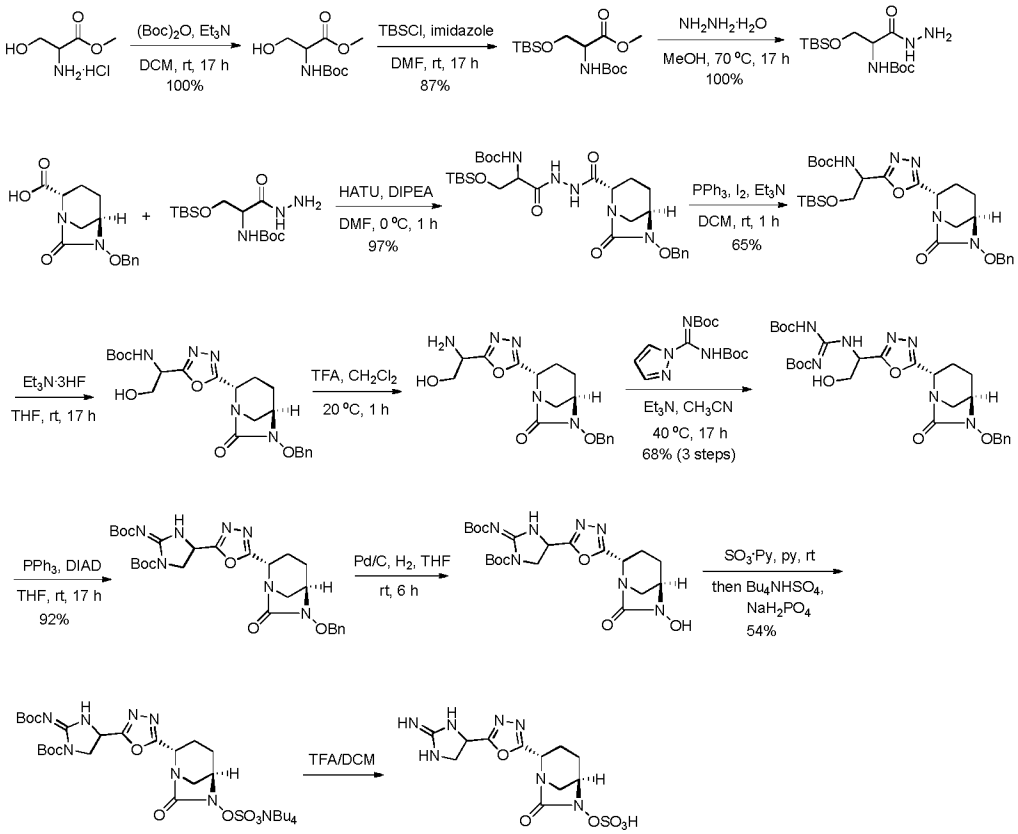




ESI-MS (EI^+, *m/z*): 362.1. ^{1}H NMR (300 MHz, D_2O) δ 4.73 (d, *J* = 6.3 Hz, 1H), 4.15 (br s, 1H), 3.28 – 3.10 (m, 1H), 3.02 – 2.79 (m, 5H), 2.38 – 2.03 (m, 4H), 2.06 – 1.45 (m, 4H).

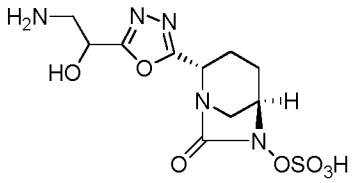
***Example 28**: Synthesis of (2S,5R)-2-(5-(2-iminoimidazolidin-4-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 767)**

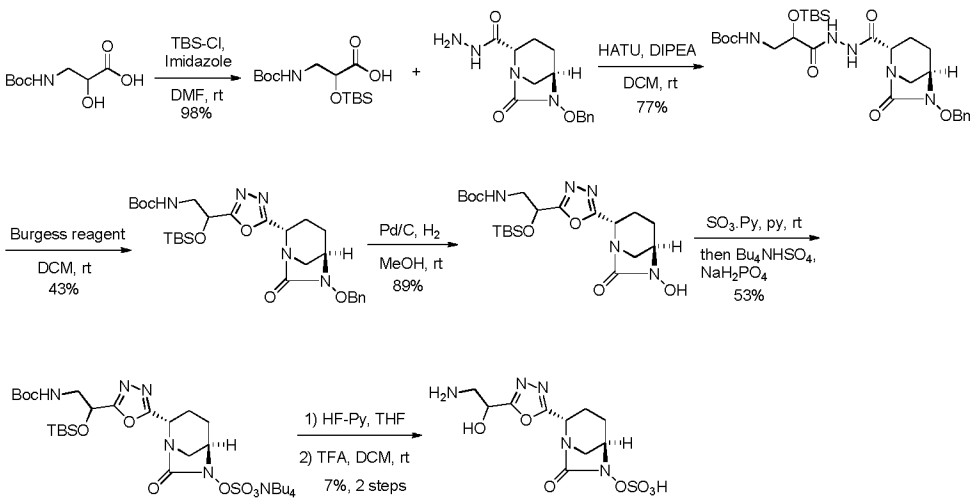




ESI-MS (EI^+, *m/z*): 374.2. ^1H NMR (300 MHz, D_2O) δ 5.41 (dd, *J* = 10.1, 4.9 Hz, 1H), 4.76 (d, *J* = 6.3 Hz, 1H), 4.26 – 4.00 (m, 2H), 3.98 – 3.78 (m, 1H), 3.27 – 3.09 (m, 1H), 2.90 (d, *J* = 12.4 Hz, 1H), 2.34 – 2.01 (m, 3H), 2.01 – 1.70 (m, 1H).

***Example 29**: Synthesis of (2S,5R)-2-(5-(2-amino-1-hydroxyethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 715**)*

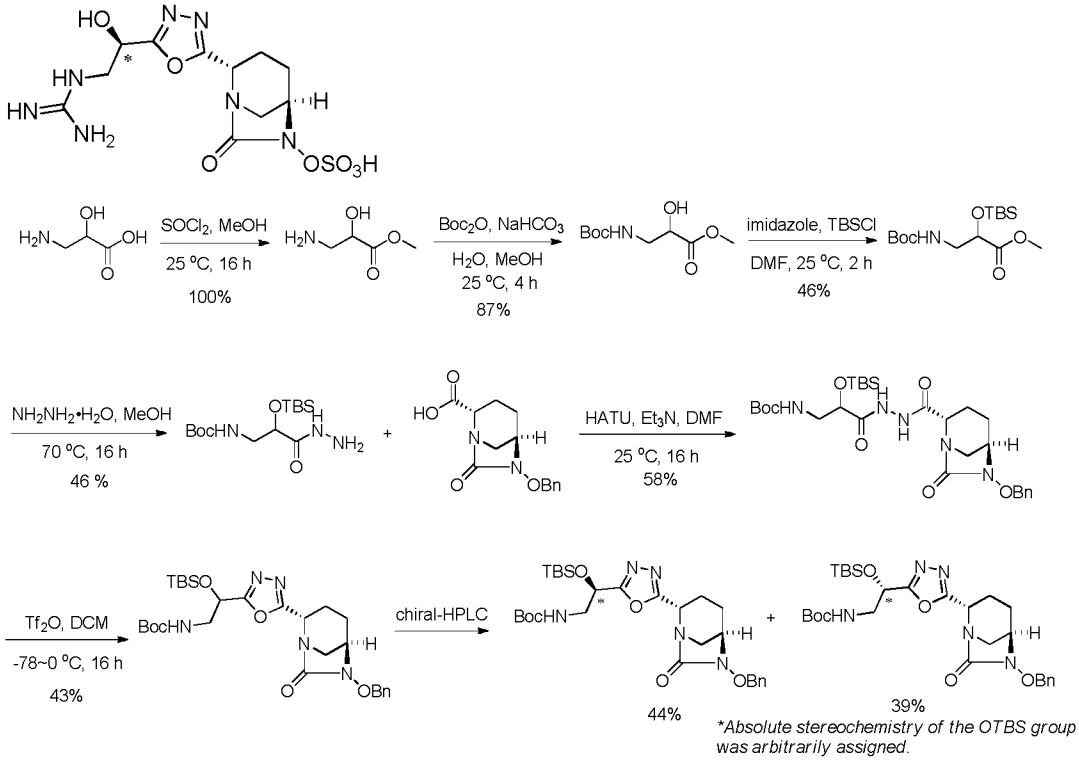


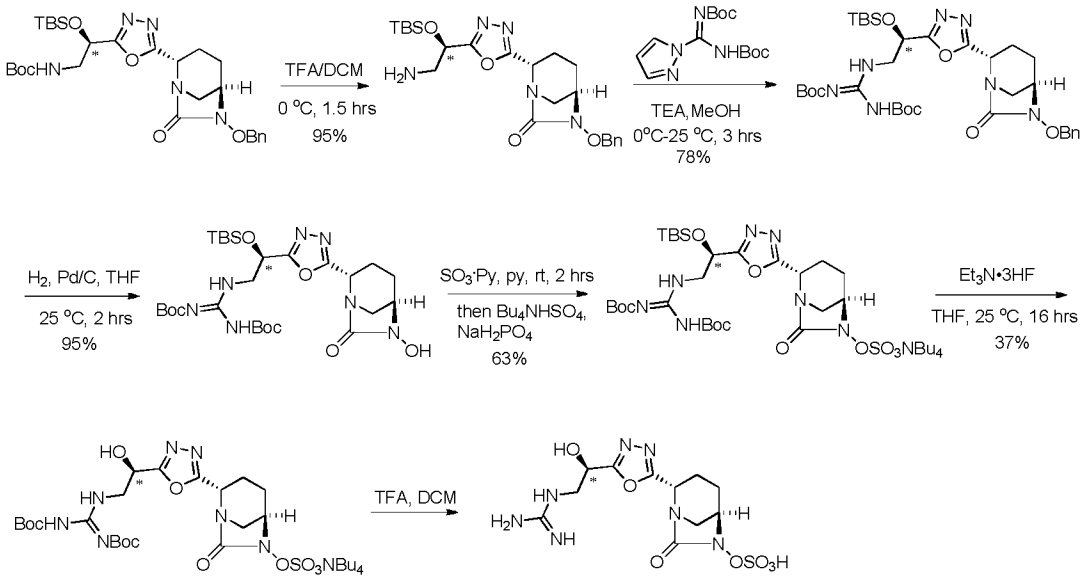


ESI-MS (EI^+, *m/z*): 350.1. ^1H NMR (300 MHz, D_2O) δ 5.25 (dd, *J* = 8.4, 3.9 Hz, 1H), 4.78 (d, *J* = 6.7 Hz, 1H), 4.22 – 4.11 (m, 1H), 3.56 – 3.32 (m, 2H), 3.23 – 3.12 (m, 1H), 2.92 (dd, *J* = 12.3, 1.4 Hz, 1H), 2.34 – 2.02 (m, 3H), 2.03 – 1.83 (m, 1H).

***Example 30**: Synthesis of (2S,5R)-2-(5-((R)-2-guanidino-1-hydroxyethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate*

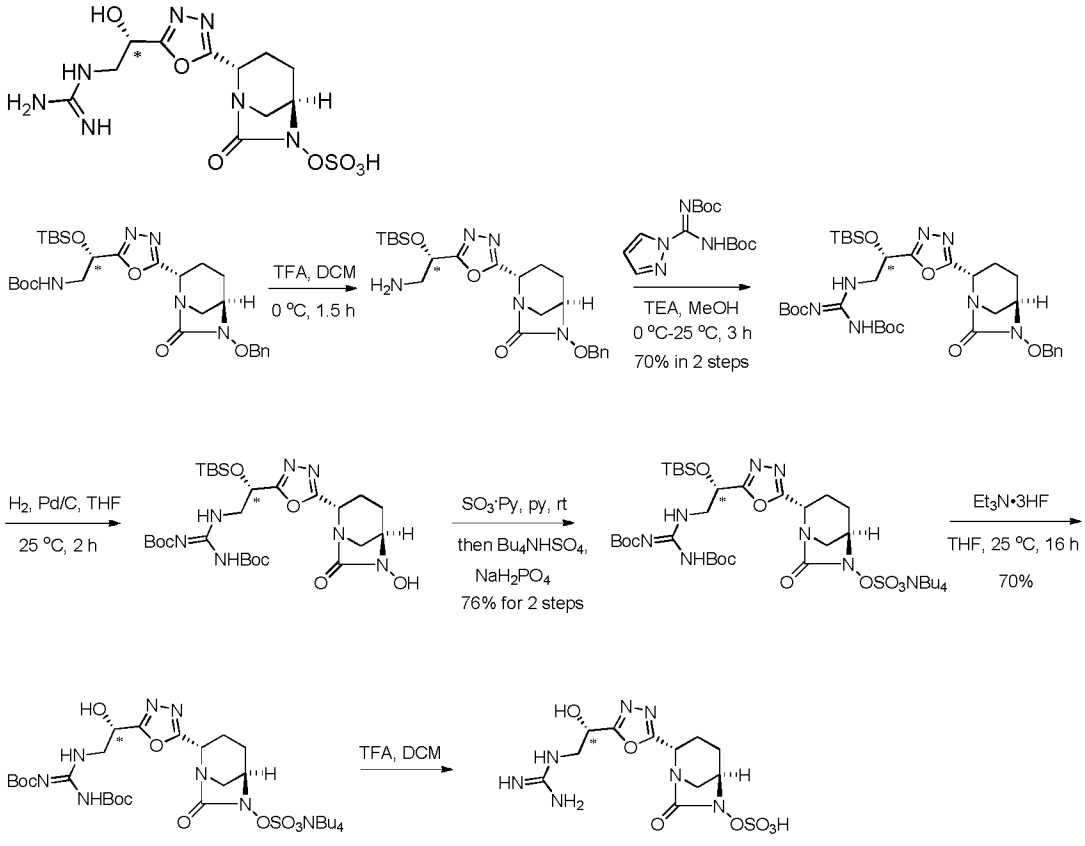
(Compound 731)





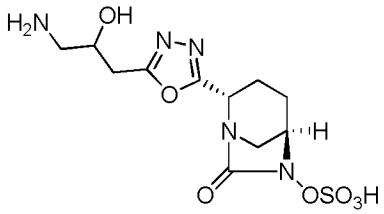
ESI-MS (EI$^+$, *m/z*): 392.2. ^{1}H NMR (300 MHz, D_2O) δ 5.15 (t, *J* = 4.9 Hz, 1H), 4.78 (d, *J* = 6.5 Hz, 1H), 4.18 (s, 1H), 3.78 – 3.57 (m, 2H), 3.26 – 3.11 (m, 1H), 2.89 (d, *J* = 12.1 Hz, 1H), 2.39 – 2.08 (m, 3H), 2.03 – 1.78 (m, 1H).

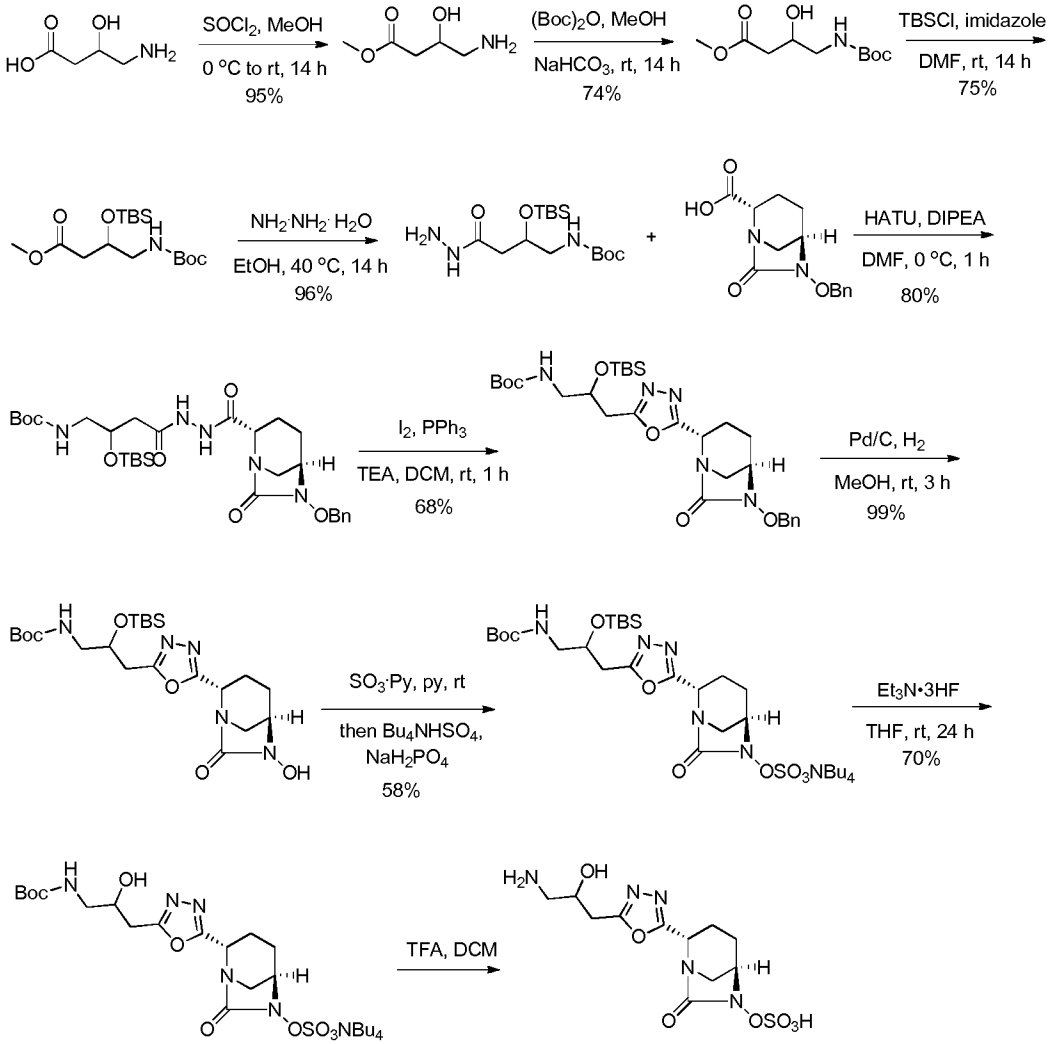
***Example 31**: Synthesis of (2S,5R)-2-(5-((S)-2-guanidino-1-hydroxyethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 732)**



ESI-MS (EI$^+$, *m/z*): 392.2. ^{1}H NMR (300 MHz, D_2O) δ 5.14 (t, *J* = 4.9 Hz,, 1H), 4.78 (d, *J* = 6.5 Hz, 1H), 4.16 (s, 1H), 3.66 (dd, *J* = 5.3, 3.2 Hz, 2H), 3.17 (br d, *J* = 12.1 Hz, 1H), 2.87 (d, *J* = 12.4 Hz, 1H), 2.35 – 2.00 (m, 3H), 1.97 - 1.85 (m, 1H).

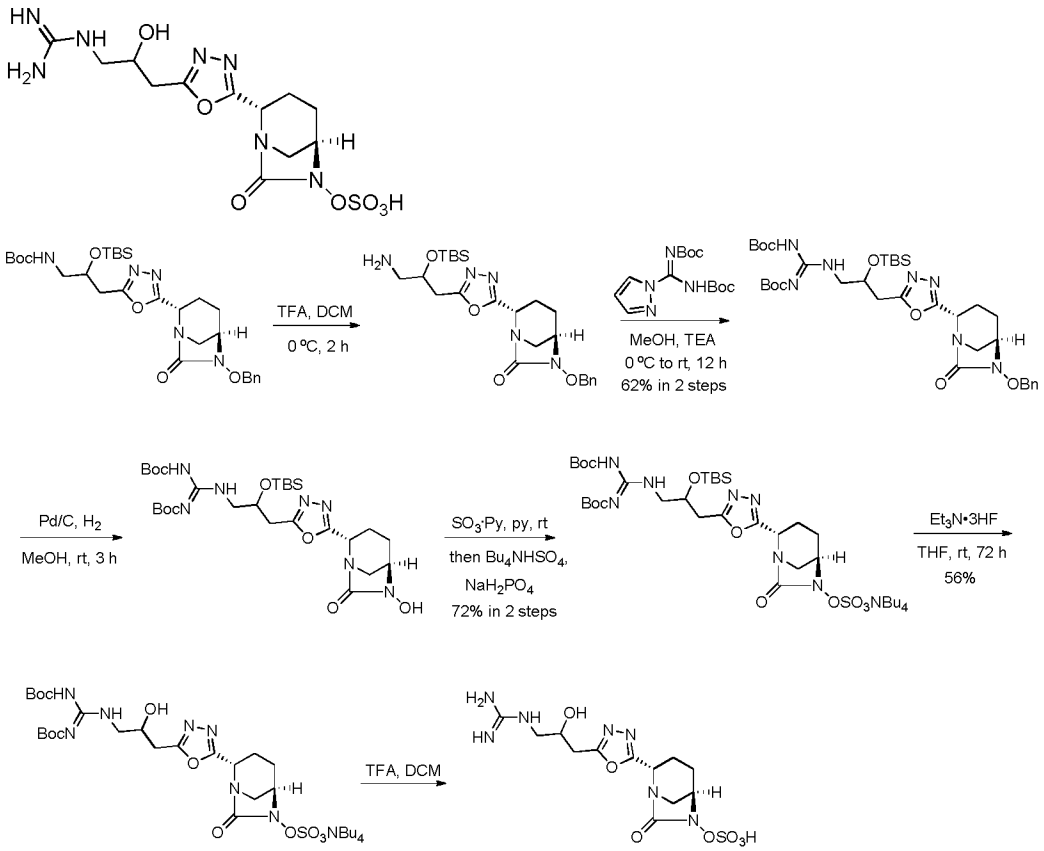
***Example 32**: Synthesis of (2S,5R)-2-(5-(3-amino-2-hydroxypropyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 733)**





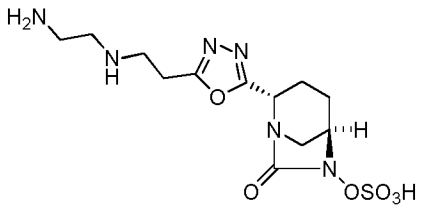
ESI-MS (EI$^+$, *m/z*): 364.2. ^{1}H NMR (300 MHz, D_2O) δ 4.77 (d, *J* = 6.5 Hz, 1H), 4.38 – 4.22 (m, 1H), 4.18 (br s, 1H), 3.46 – 2.84 (m, 6H), 2.36 – 2.03 (m, 3H), 2.05 – 1.74 (m, 1H).

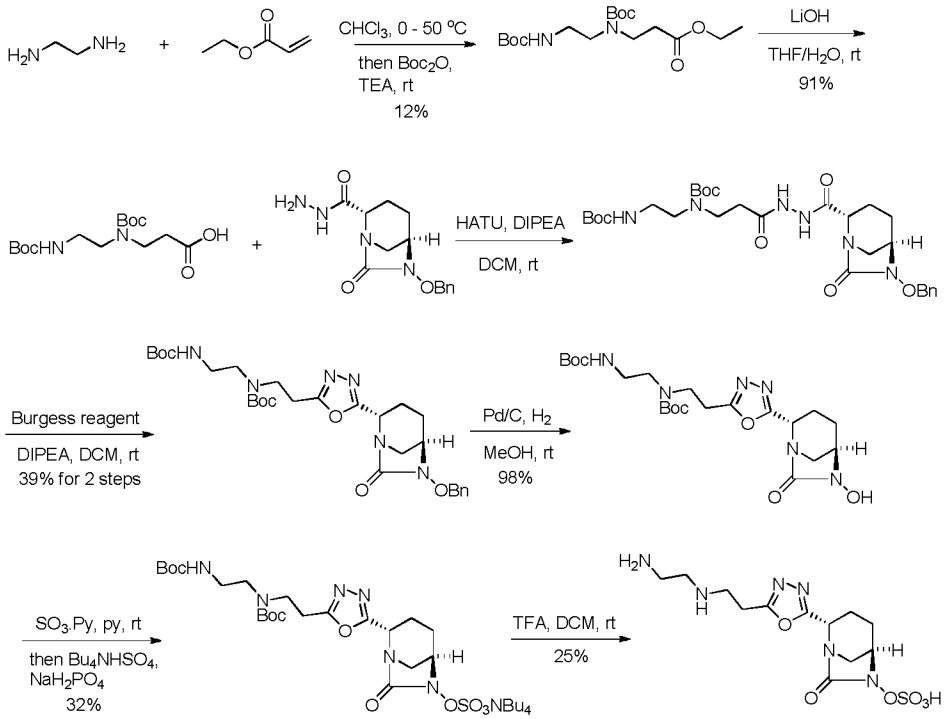
***Example 33**: Synthesis of (2S,5R)-2-(5-(3-guanidino-2-hydroxypropyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 730**)**



ESI-MS (EI^+, *m/z*): 406.2. ^{1}H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 6.5 Hz, 1H), 4.41 – 4.03 (m, 2H), 3.37 (d, *J* = 10.8 Hz, 1H), 3.31 – 2.95 (m, 4H), 2.89 (d, *J* = 12.1 Hz, 1H), 2.34–2.02 (m, 3H), 2.02 – 1.78 (m, 1H).

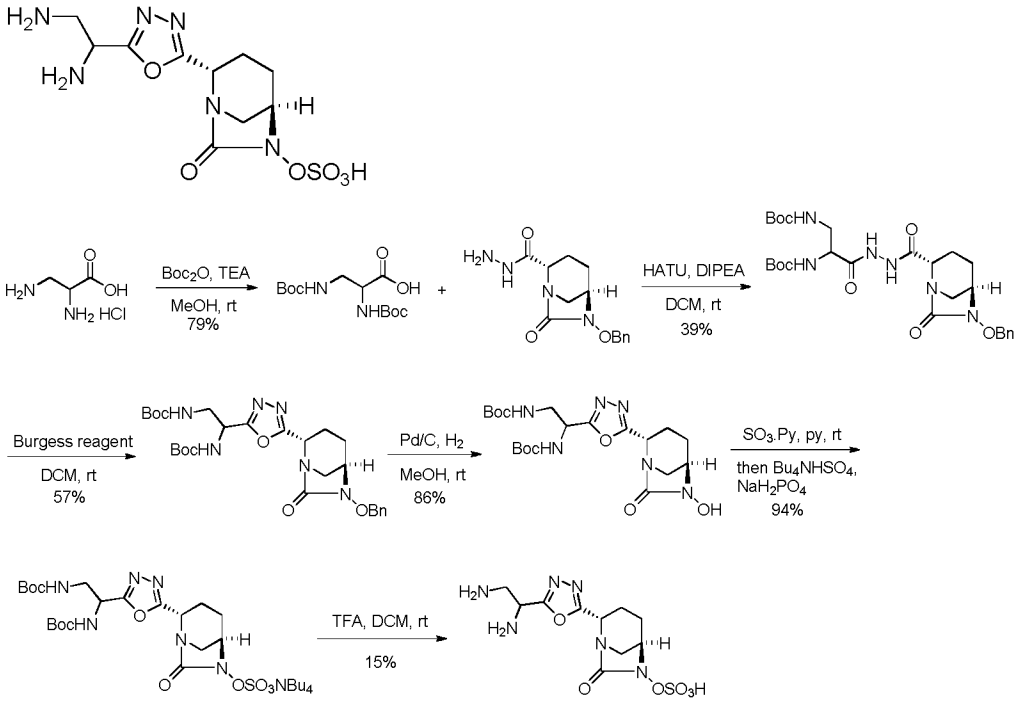
***Example 34** : Synthesis of (2S,5R)-2-(5-(2-((2-aminoethyl)amino)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 716**)**





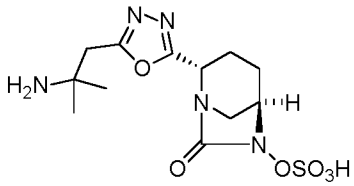
ESI-MS (EI^+, *m/z*): 377.3. ^1H NMR (300 MHz, D_2O) δ 4.78 (d, *J* = 6.7 Hz, 1H), 4.20 (br s, 1H), 3.57 – 3.42 (m, 2H), 3.42 – 3.26 (m, 6H), 3.26 – 3.11 (m, 1H), 2.95 (d, *J* = 12.3 Hz, 1H), 2.33 – 2.07 (m, 3H), 2.06 – 1.83 (m, 1H).

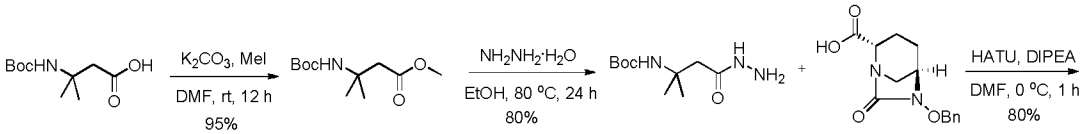
***Example 35**: Synthesis of (2S,5R)-2-(5-(1,2-diaminoethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 717**)*

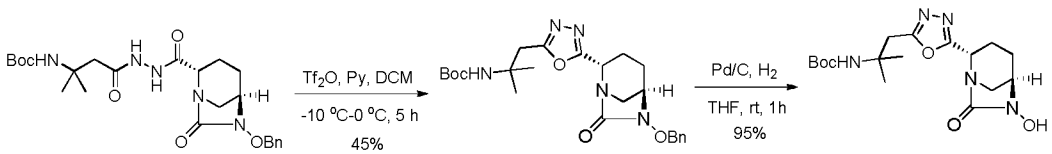


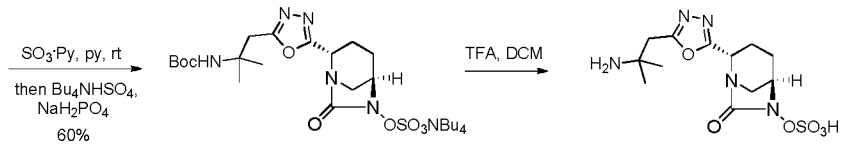
ESI-MS (EI$^+$, *m/z*): 349.2. ^{1}H NMR (300 MHz, D_2O) δ 4.79 (d, *J* = 6.5 Hz, 1H), 4.56 – 4.43 (m, 1H), 4.19 (br s, 1H), 3.52 – 3.41 (m, 1H), 3.35 – 3.13 (m, 2H), 2.97 (d, *J* = 12.4 Hz, 1H), 2.35 – 2.09 (m, 3H), 2.09 – 1.81 (m, 1H).

***Example 36**: Synthesis of (2S,5R)-2-(5-(2-amino-2-methylpropyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 737)**



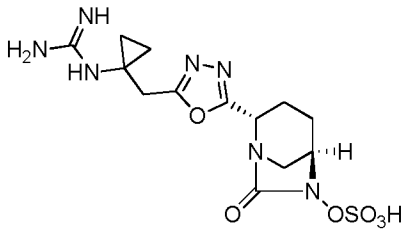


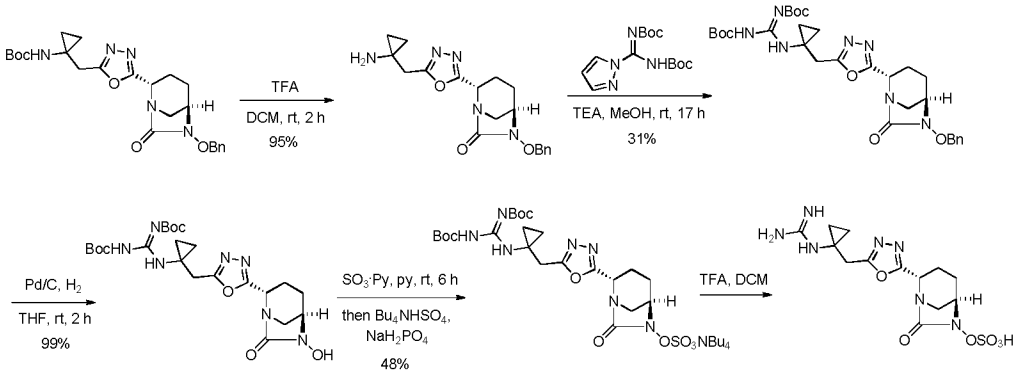




ESI-MS (EI$^+$, *m/z*): 362.3. ^{1}H NMR (300 MHz, D_2O) δ 4.78 (d, *J* = 7.3 Hz, 1H), 4.18 (br s, 1H), 3.28 (s, 2H), 3.20-3.06 (m, 1H), 2.94 (d, *J* = 12.3 Hz, 1H), 2.34 – 2.07 (m, 3H), 2.01 – 1.87 (m, 1H), 1.41 – 1.33 (m, 6H).

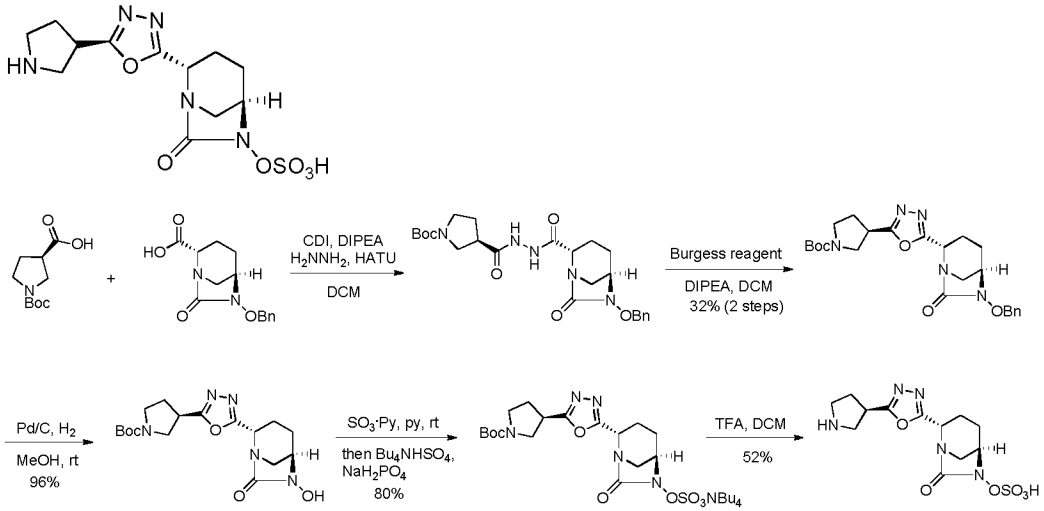
***Example 37**: Synthesis of (2S,5R)-2-(5-((1-guanidinocyclopropyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 739)**





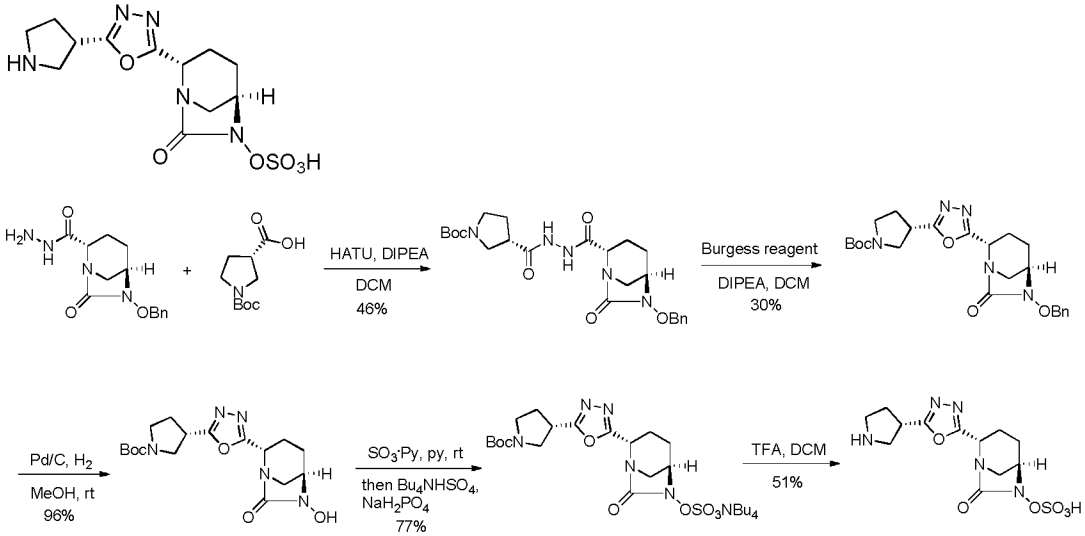
ESI-MS (EI$^+$, *m/z*): 402.3. ^{1}H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 6.4 Hz, 1H), 4.17 (br s, 1H), 3.27 – 3.00 (m, 3H), 2.90 (d, *J* = 12.3 Hz, 1H), 2.36 – 2.04 (m, 3H), 2.03 – 1.79 (m, 1H), 1.09 – 0.84 (m, 4H).

Example 38 *: Synthesis of (2S,5R)-7-oxo-2-(5-((R)-pyrrolidin-3-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 759)***



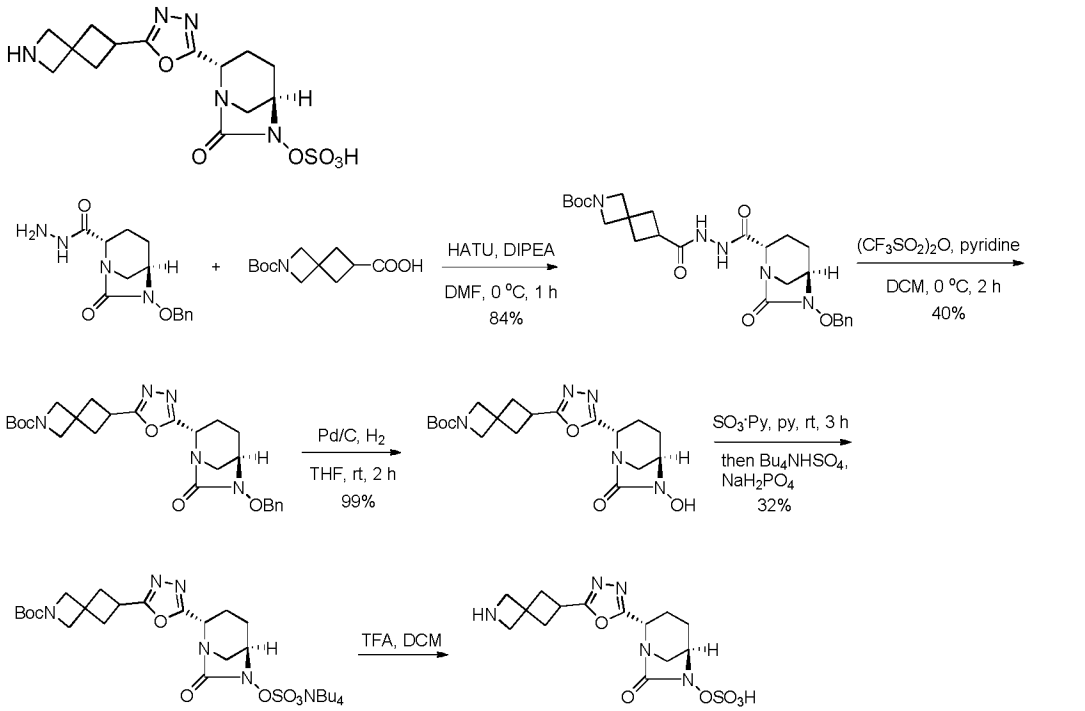
ESI-MS (EI$^+$, *m/z*): 360.1. ^{1}H NMR (300 MHz, D_2O) δ 4.78 (d, *J* = 6.4 Hz, 1H), 4.20 (br s, 1H), 4.05 – 3.95 (m, 1H), 3.83 – 3.71 (m, 1H), 3.68 – 3.54 (m, 1H), 3.54 – 3.38 (m, 2H), 3.26 – 3.16 (m, 1H), 2.94 (d, *J* = 12.3 Hz, 1H), 2.62 – 2.45 (m, 1H), 2.43 – 2.09 (m, 4H), 2.04 – 1.85 (m, 1H).

Example 39*: Synthesis of (2S,5R)-7-oxo-2-(5-((S)-pyrrolidin-3-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 758)***



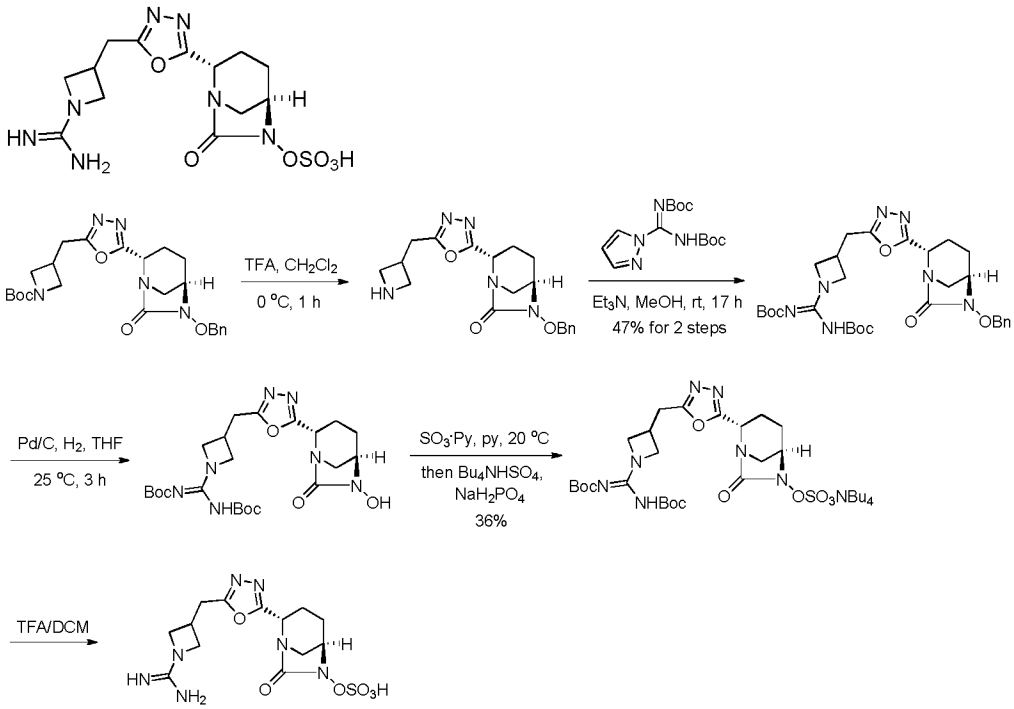
ESI-MS (EI$^+$, *m/z*): 360.1.

***Example 40**: Synthesis of (2S,5R)-2-(5-(2-azaspiro[3.3]heptan-6-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 750**)*



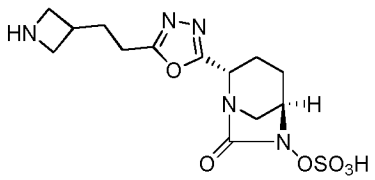
ESI-MS (EI$^+$, *m/z*): 386.3.

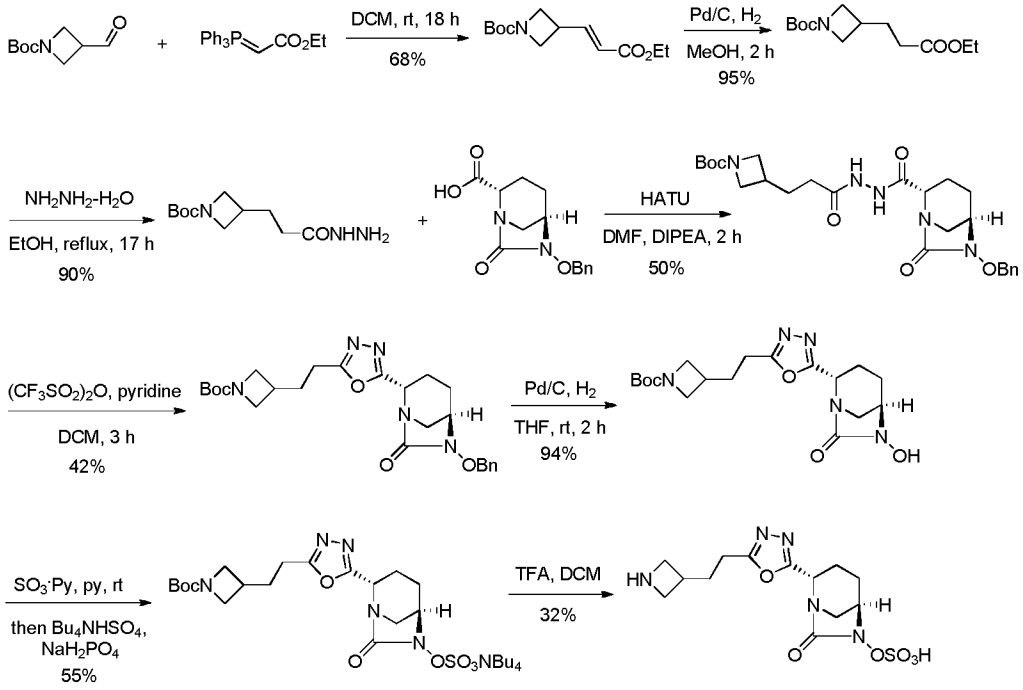
***Example 41**: Synthesis of (2S,5R)-2-(5-((1-carbamimidoylazetidin-3-yl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 741**)*



ESI-MS (EI^+, *m/z*): 402.1. ^1H NMR (300 MHz, DMSO-d_6) δ 4.63 (d, *J* = 6.4 Hz, 1H), 4.27 – 4.12 (m, 2H), 4.07 (br s, 1H), 3.84 (dd, *J* = 8.7, 4.8 Hz, 2H), 3.32 – 3.25 (m, 3H), 3.03 – 2.89 (m, 1H), 2.71 (d, *J* = 11.9 Hz, 1H), 2.21 – 2.10 (m, 1H), 2.08 – 1.94 (m, 2H), 1.94 – 1.79 (m, 1H).

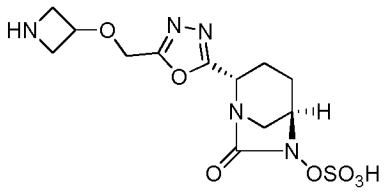
***Example 42**: Synthesis of (2S,5R)-2-(5-(2-(azetidin-3-yl)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 742**)*

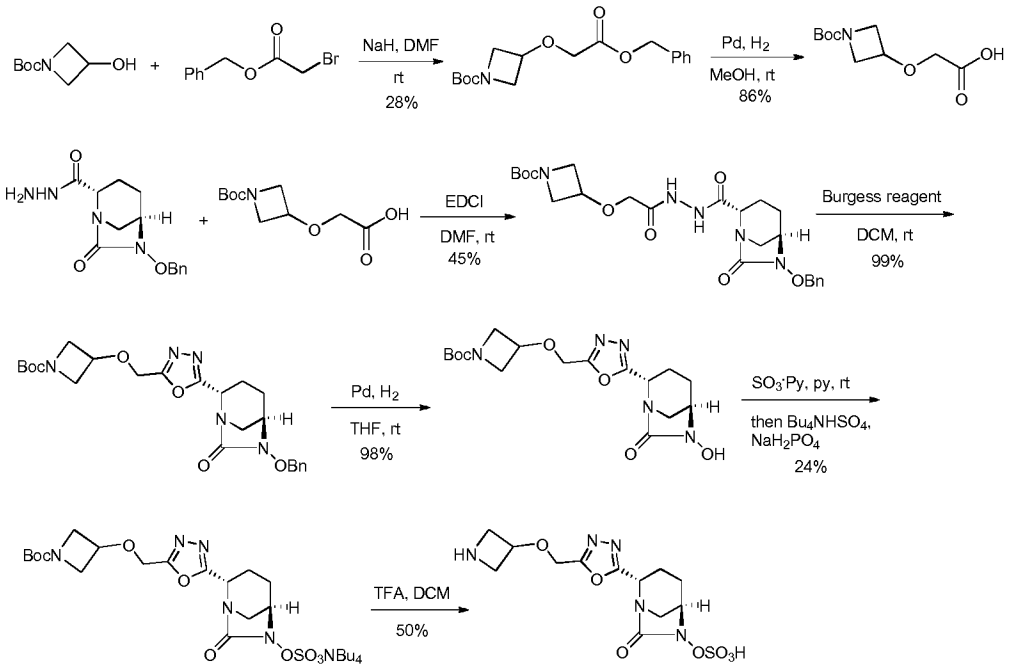




ESI-MS (EI$^+$, *m/z*): 374.2. ^{1}H NMR (300 MHz, D_2O) δ 4.73 (d, *J* = 6.4 Hz, 1H), 4.16 (brs, 1H), 4.12 – 4.00 (m, 2H), 3.81 – 3.71 (m, 2H), 3.22 – 3.09 (m, 1H), 3.02 – 2.74 (m, 4H), 2.32 – 1.76 (m, 6H).

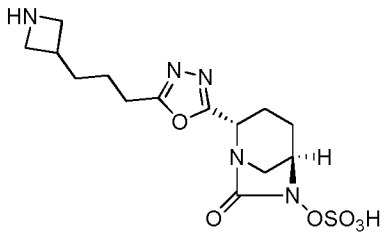
***Example 43**: Synthesis of (2S,5R)-2-(5-((azetidin-3-yloxy)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 744**)*

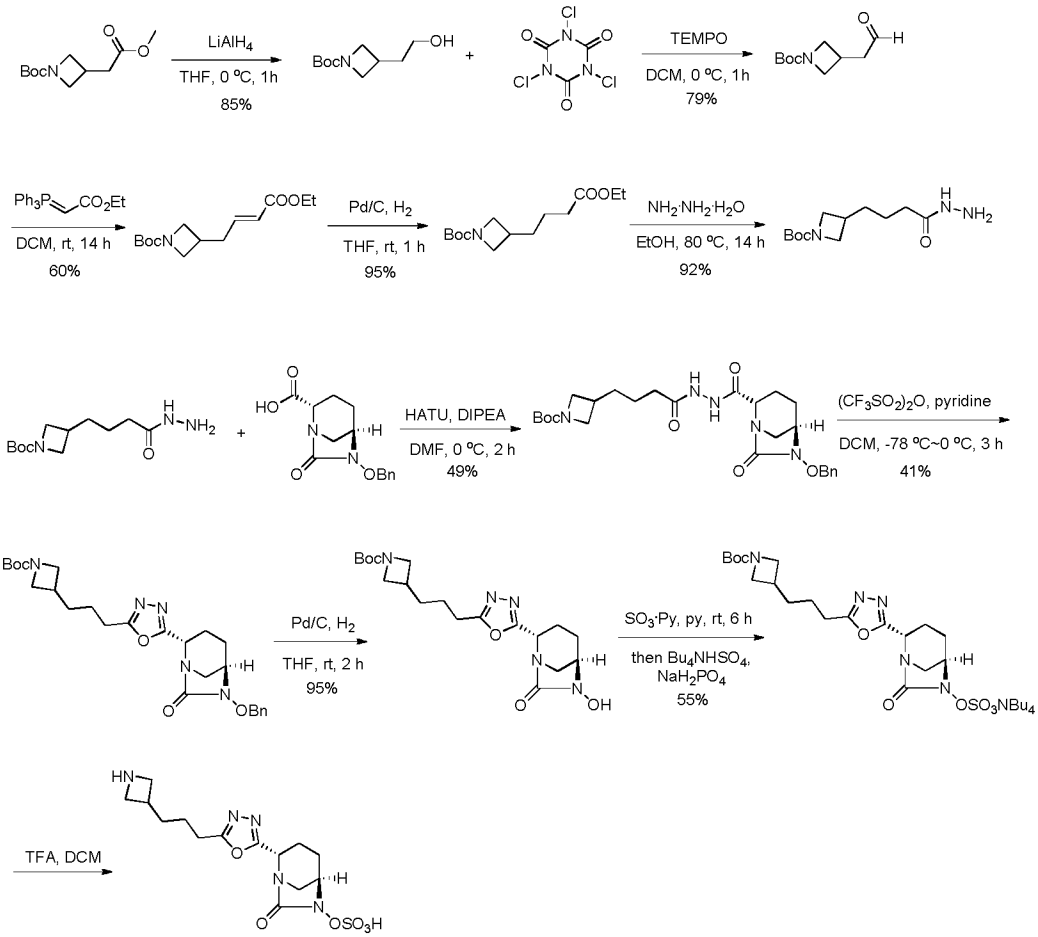




ESI-MS (EI^+, *m/z*): 376.2. ^1H NMR (300 MHz, D_2O) δ 4.78 (s, 2H), 4.74 (d, *J* = 6.4 Hz, 1 H), 4.66 – 4.56 (m, 1H), 4.34 – 4.22 (m, 2H), 4.16 (br s, 1H), 4.06 – 3.91 (m, 2H), 3.23 – 3.04 (m, 1H), 2.88 (d, *J* = 12.3 Hz, 1H), 2.35 – 2.00 (m, 3H), 2.00 – 1.80 (m, 1H).

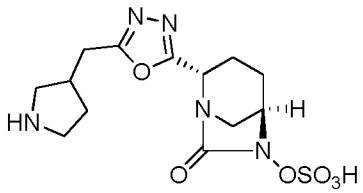
***Example 44**: Synthesis of (2S,5R)-2-(5-(3-(azetidin-3-yl)propyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 743**)*

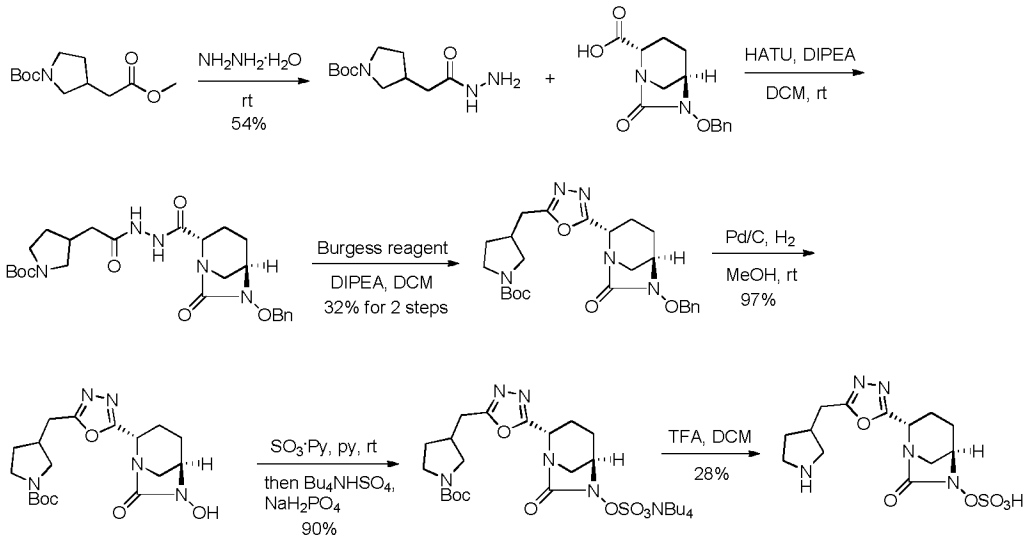




ESI-MS (EI$^+$, *m/z*): 388.2. ^{1}H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 6.5 Hz, 1H), 4.16 (br s, 1H), 4.11 – 3.99 (m, 2H), 3.72 (dd, *J* = 11.4, 7.6 Hz, 2H), 3.22 – 3.10 (m, 1H), 2.95 – 2.74 (m, 4H), 2.34 – 2.03 (m, 3H), 2.01 – 1.77 (m, 1H), 1.72 – 1.50 (m, 4H).

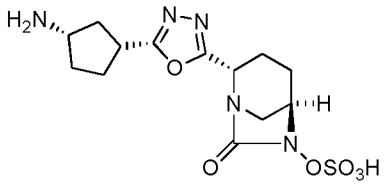
Example 45*: Synthesis of (2S,5R)-7-oxo-2-(5-(pyrrolidin-3-ylmethyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 764)***

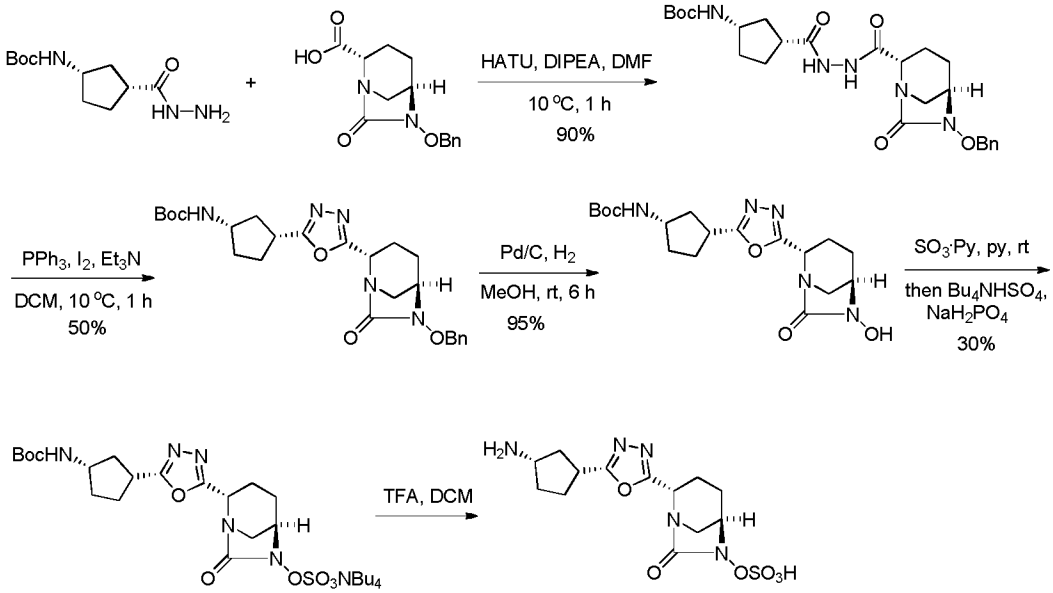




ESI-MS (EI$^+$, *m/z*): 374.2. ^{1}H NMR (300 MHz, D_2O) δ 4.74 (d, *J* = 6.4 Hz, 1H), 4.16 (br s, 1H), 3.50 (dd, *J* = 11.8, 7.7 Hz, 1H), 3.45 – 3.31 (m, 1H), 3.30 – 3.10 (m, 2H), 3.11 – 2.68 (m, 5H), 2.33 – 2.02 (m, 4H), 2.01-1.80 (m, 1H), 1.80-1.53 (m, 1H).

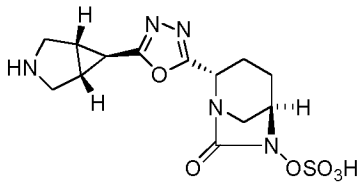
***Example 46**: Synthesis of (2S,5R)-2-(5-((1R,3S)-3-aminocyclopentyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 768**)**

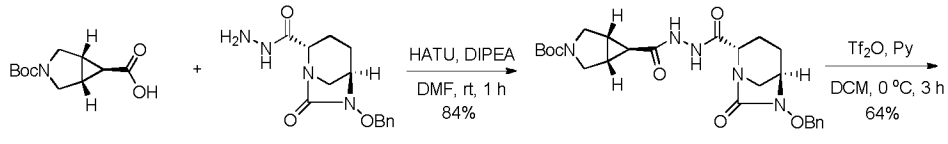


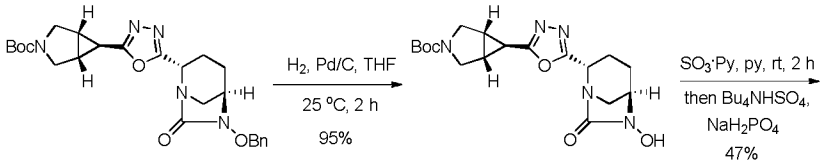


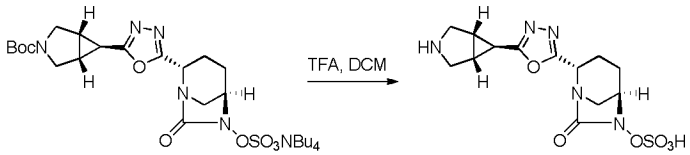
ESI-MS (EI$^+$, *m/z*): 374.3.

***Example 47**: Synthesis of (2S,5R)-2-(5-(3-azabicyclo[3.1.0]hexan-6-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 740**)**



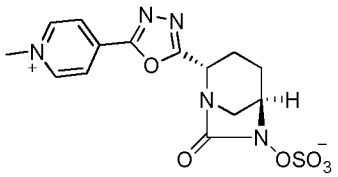


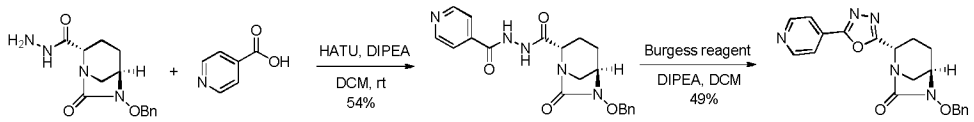


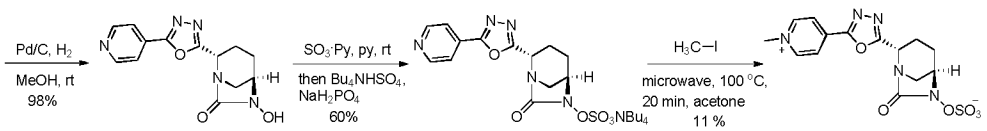


ESI-MS (EI$^+$, *m/z*): 372.3.

***Example 48**: Synthesis of (2S,5R)-2-(5-(1-methylpyridin-1-ium-4-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate* (**Compound782**)**



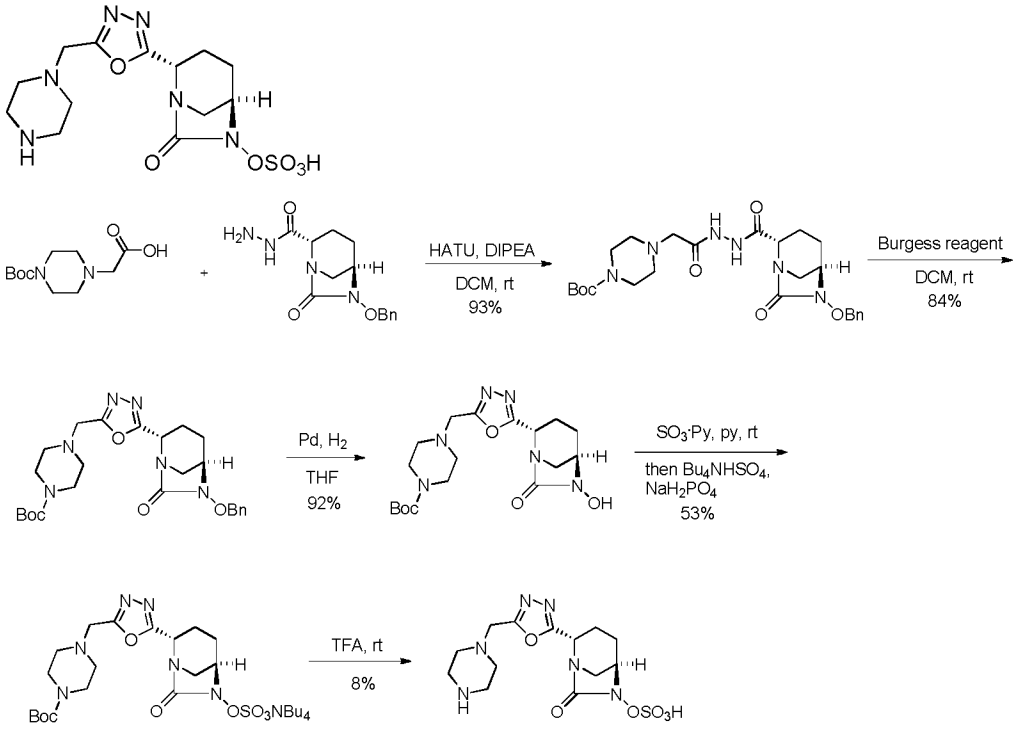




ESI-MS (EI$^+$, *m/z*): 382.1. ^{1}H NMR (300 MHz, D_2O) δ 8.95 (d, *J* = 6.8 Hz, 2H), 8.53 (d, *J* =

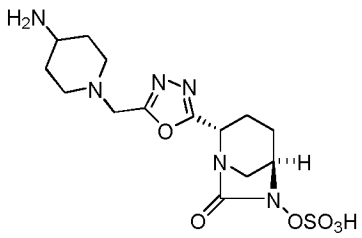
6.9 Hz, 2H), 4.92 (d, *J* = 7.0 Hz, 1H), 4.38 (s, 3H), 4.20 (br s, 1H), 3.22 (br d, *J* = 13.2 Hz, 1H), 2.98 (d, *J* = 12.4 Hz, 1H), 2.42-2.33 (m, 1H), 2.31-2.10 (m, 2H), 2.03 – 1.90 (m, 1H).

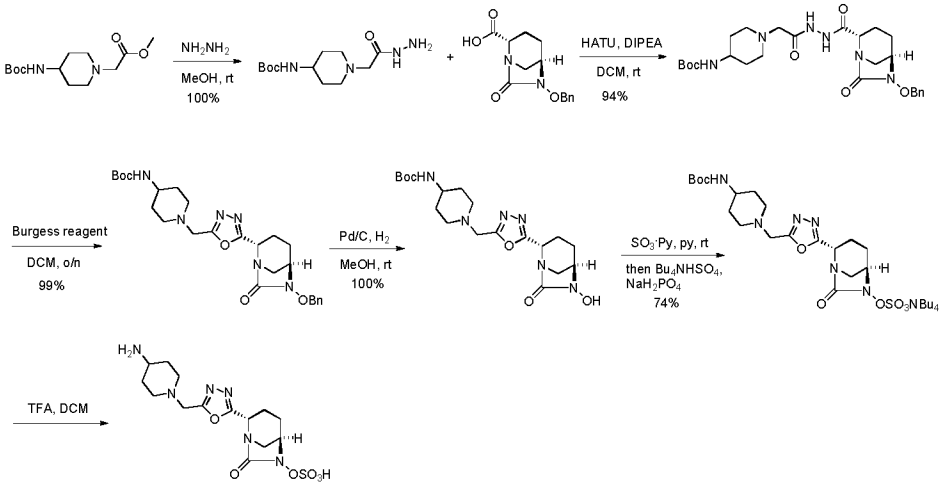
***Example 49**: Synthesis of (2S,5R)-7-oxo-2-(5-(piperazin-1-ylmethyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 777**)*



ESI-MS (EI^+, *m/z*): 389.2. ^1H NMR (300 MHz, D_2O) δ 4.77 (d, *J* = 6.4 Hz, 1H), 4.16 (br s, 1H), 3.96 (s, 2H), 3.22 – 3.11 (m, 5H), 2.88 (d, *J* = 12.3 Hz, 1H), 2.85 – 2.76 (m, 4H), 2.31 – 2.02 (m, 3H), 1.98 – 1.78 (m, 1H).

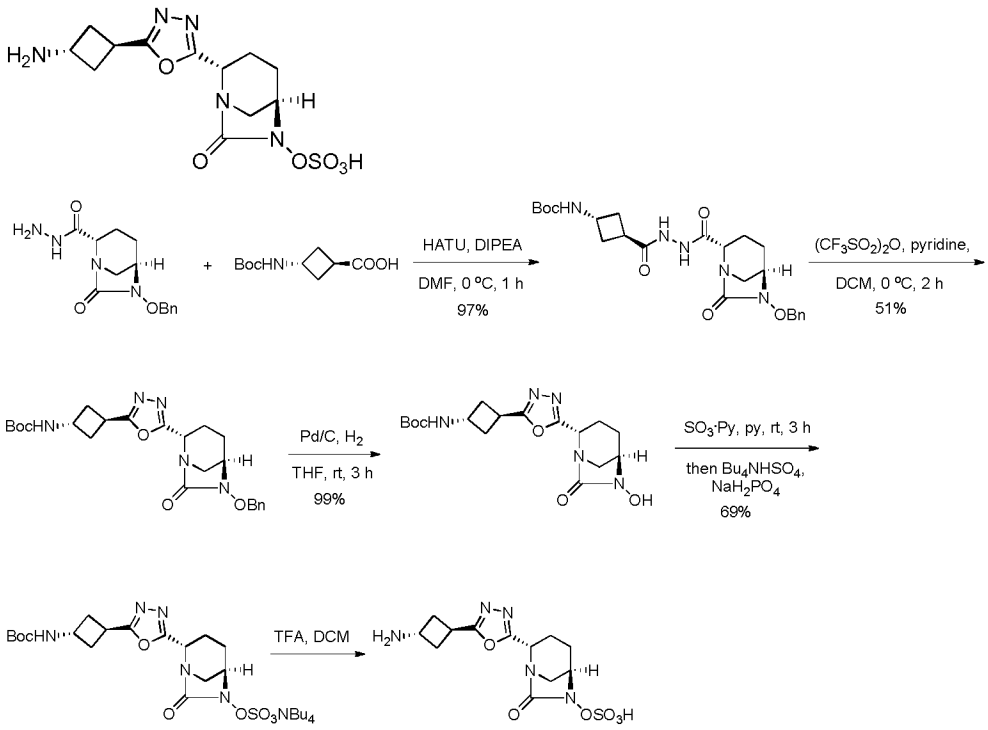
***Example 50**: Synthesis of (2S,5R)-2-(5-((4-aminopiperidin-1-yl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 774**)*





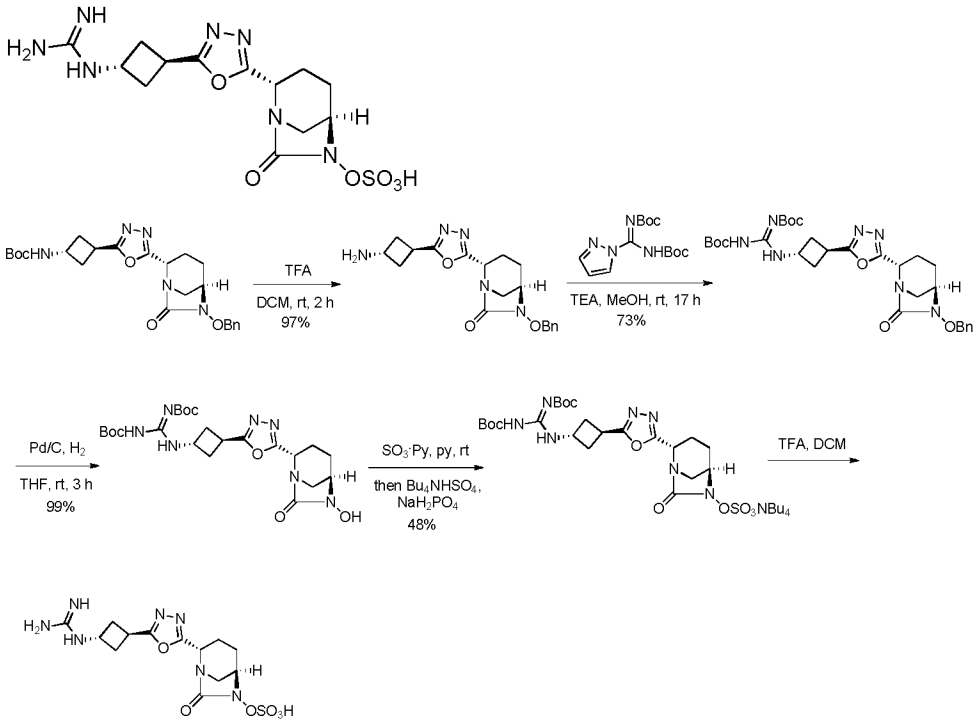
ESI-MS (EI$^+$, *m/z*): 403.2. ^{1}H NMR (300 MHz, D_2O) δ 4.77 (d, *J* = 6.5 Hz, 1H), 4.16 (br s, 1H), 3.87 (s, 2H), 3.20 – 3.05 (m, 2H), 3.00-2.91 (m, 2H), 2.87 (d, *J* = 12.3 Hz, 1H), 2.32 – 2.04 (m, 5H), 2.03 – 1.85 (m, 3H), 1.57 (q, *J* = 11.7 Hz, 2H).

***Example 51**: Synthesis of (2S, 5R)-2-(5-((1r, 3S)-3-aminocyclobutyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diaza-bicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 747**)**



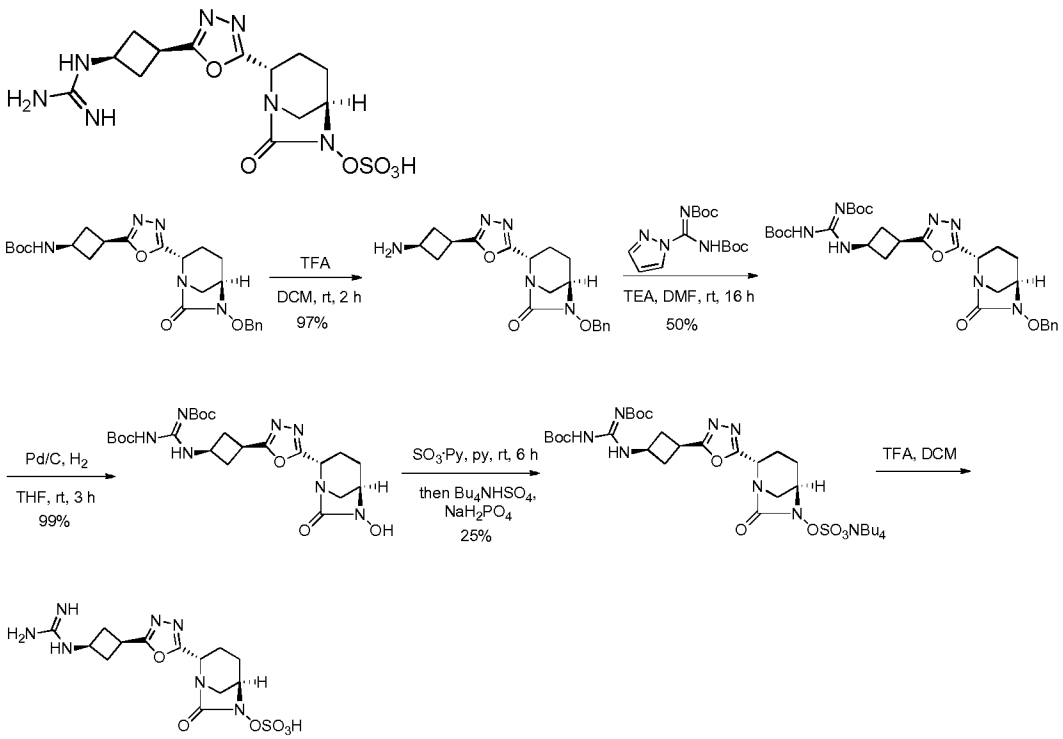
ESI-MS (EI$^+$, *m/z*): 360.2.

***Example 52**: Synthesis of (2S,5R)-2-(5-((1r,3S)-3-guanidinocyclobutyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 748**)**



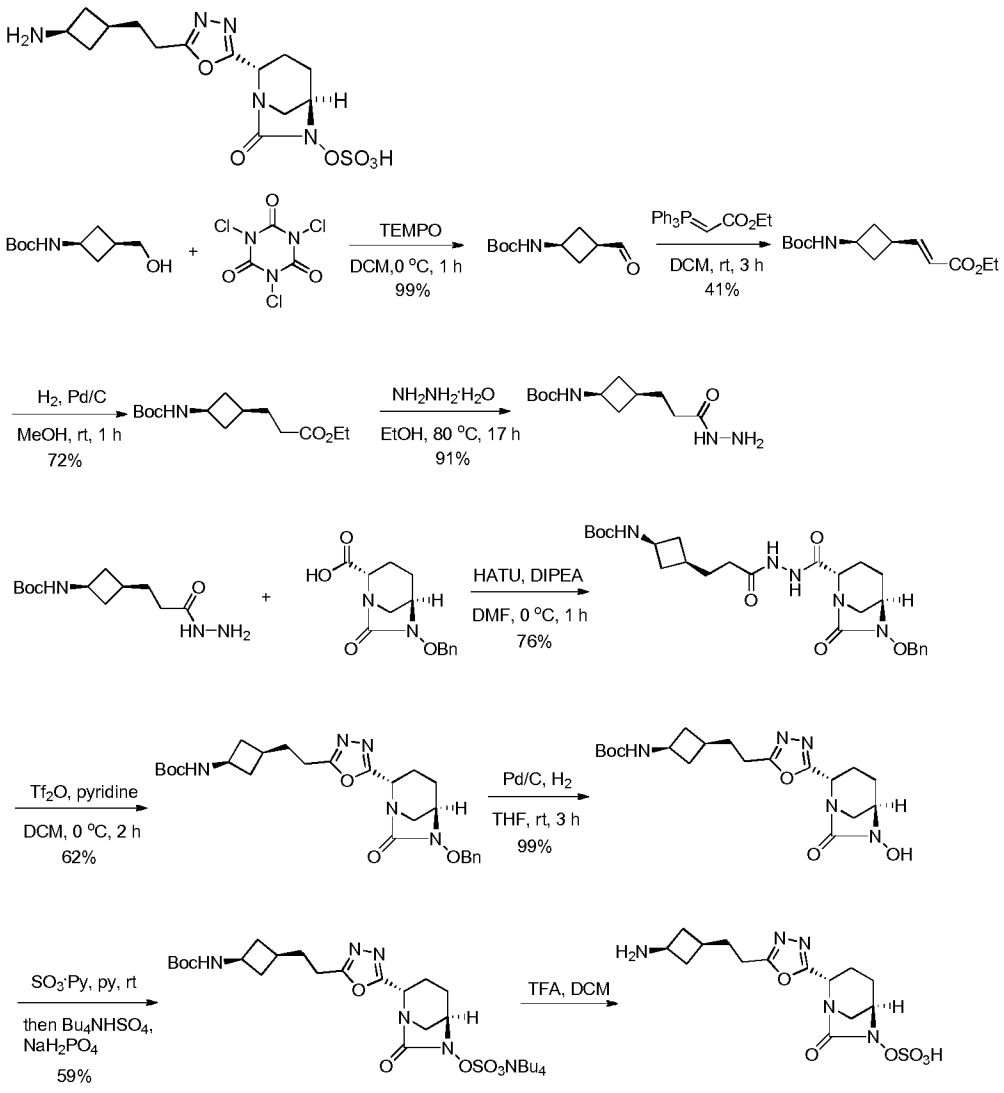
ESI-MS (EI^+, *m/z*): 402.3.

Example 53: (2S,5R)-2-(5-((1s,3R)-3-guanidinocyclobutyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate **(Compound 749)**



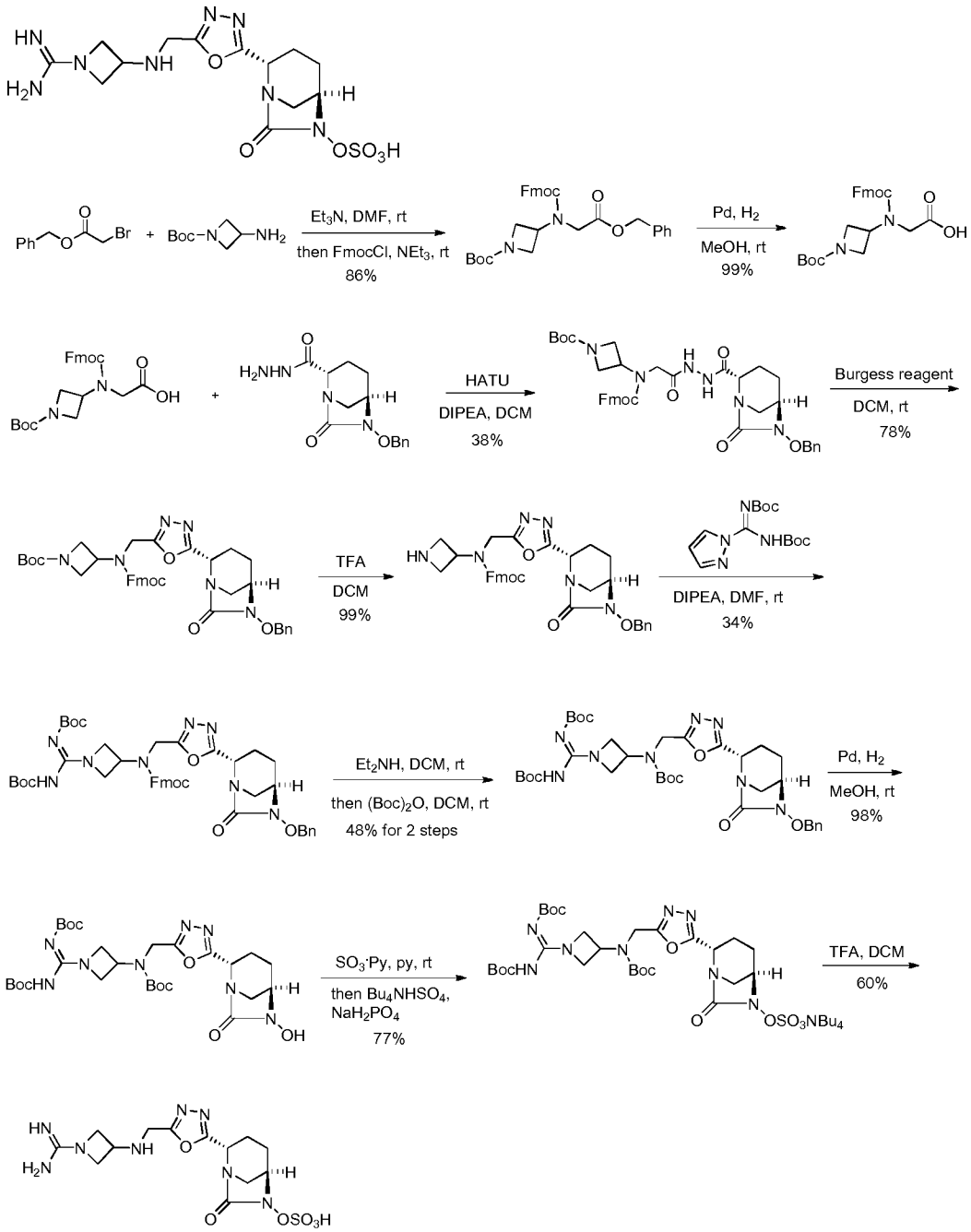
ESI-MS (EI^+, *m/z*): 402.2.

***Example 54**: Synthesis of (2S,5R)-2-(5-(2-((1s,3S)-3-aminocyclobutyl)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 754)**



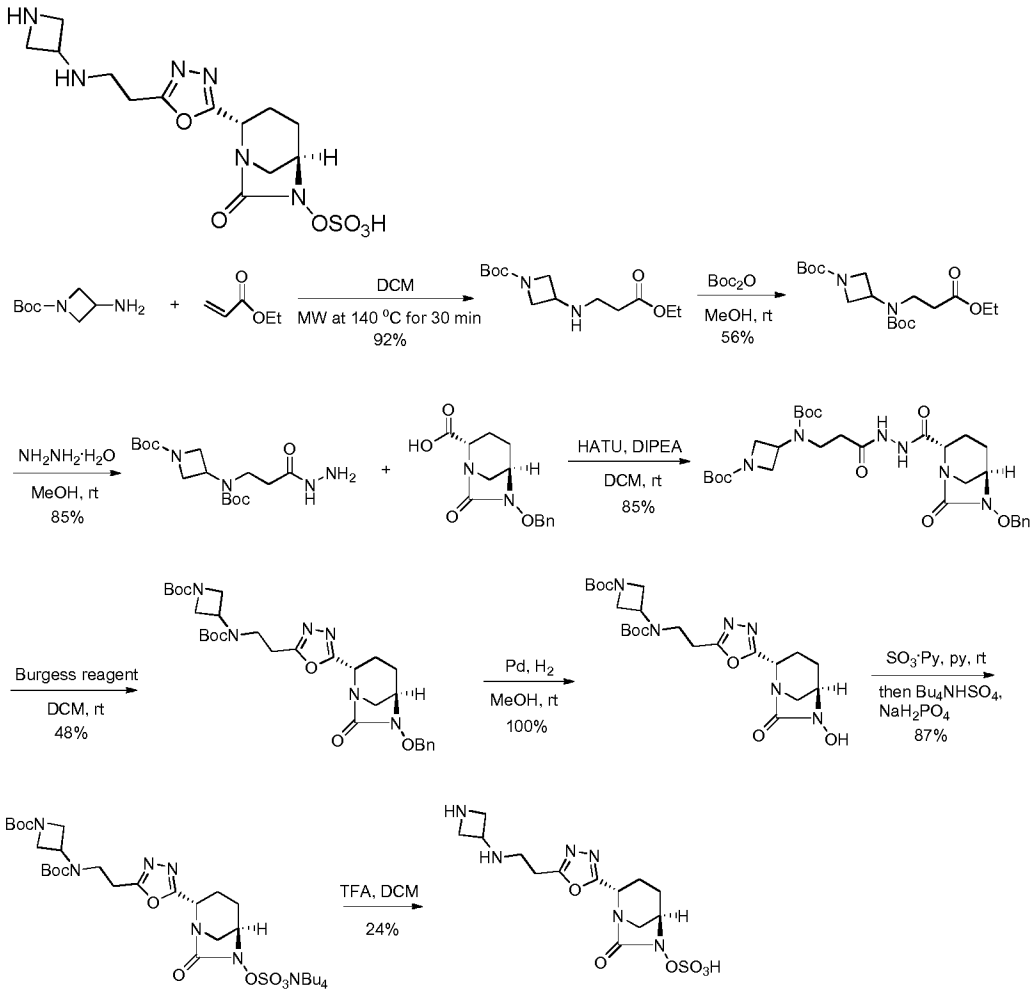
ESI-MS (EI$^+$, *m/z*): 388.2. ^{1}H NMR (300 MHz, D_2O) δ 4.68 (d, *J* = 6.5 Hz, 1H), 4.11 (br s, 1H), 3.56-3.45 (m, 1H), 3.10 (br d, *J* = 12.4 Hz, 1H), 2.86 – 2.67 (m, 3H), 2.38 – 1.94 (m, 6H), 1.95-1.70 (m, 3H), 1.66-1.52 (m, 2H).

***Example 55**: Synthesis of (2S,5R)-2-(5-(((1-carbamimidoylazetidin-3-yl)amino)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 746)**



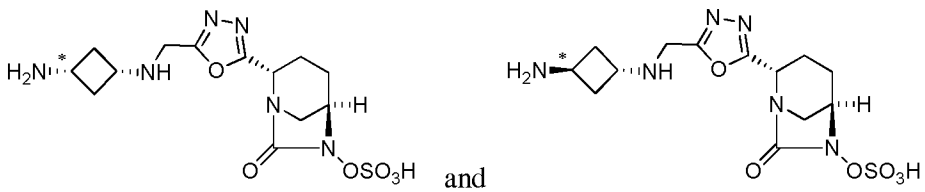
ESI-MS (EI^+, *m/z*): 417.1. ^{1}H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 5.8 Hz, 1H), 4.26 – 4.15 (m, 3H), 4.00 (s, 2H), 3.82 – 3.72 (m, 3H), 3.21 – 3.12 (m, 1H), 2.88 (d, *J* = 12.3 Hz, 1H), 2.32 – 2.02 (m, 3H), 1.99 – 1.84 (m, 1H).

***Example 56**: Synthesis of (2S,5R)-2-(5-(2-(azetidin-3-ylamino)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 745**)*

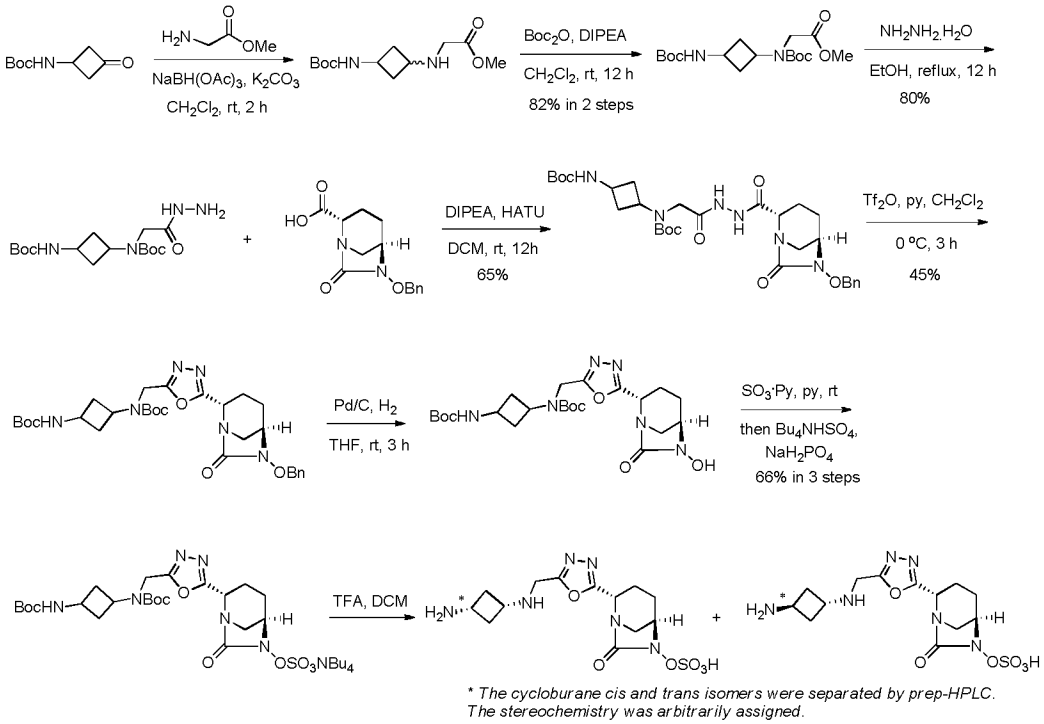


ESI-MS (EI^+, *m/z*): 389.2.

Example 57**: Synthesis of (2S,5R)-2-(5-((((1s,3R)-3-aminocyclobutyl)amino)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate **(Compound 756)** and (2S,5R)-2-(5-((((1r,3S)-3-aminocyclobutyl)amino)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate **(Compound 757)



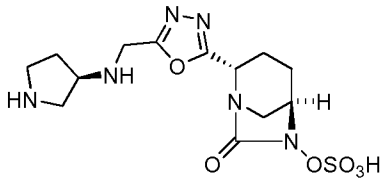
and

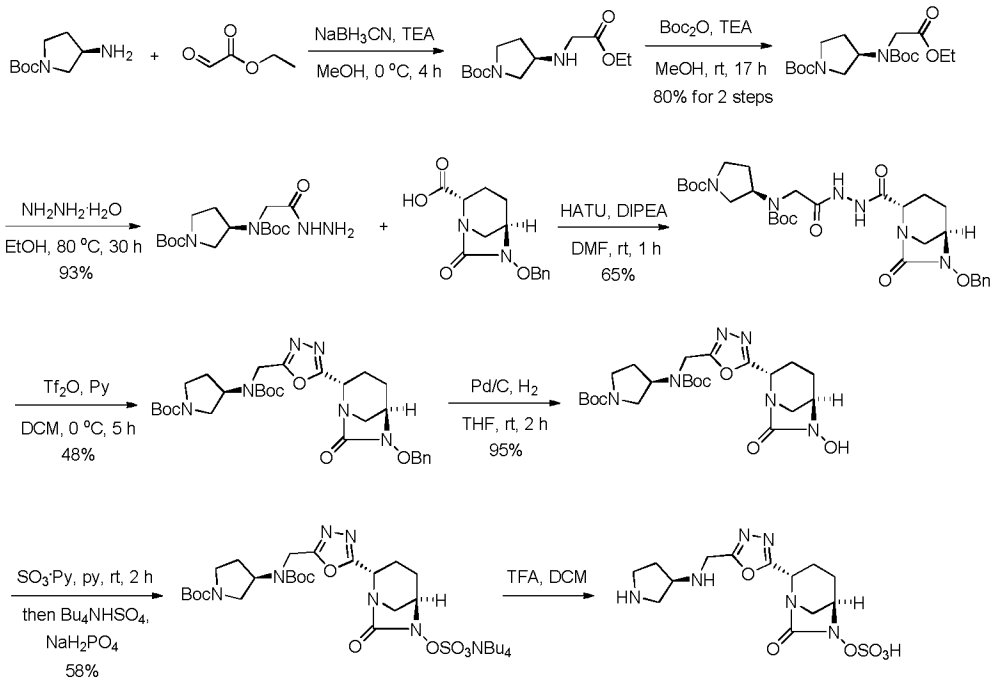


(2S,5R)-2-(5-((((1s,3R)-3-aminocyclobutyl)amino)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate **(Compound 756):** ESI-MS (EI^+, *m/z*): 389.2. ^1H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 6.5 Hz, 1H), 4.15 (br s, 1H), 3.91 (s, 2H), 3.85 – 3.60 (m, 1H), 3.60 – 3.35 (m, 1H), 3.31 – 3.04 (m, 1H), 2.86 (d, *J* = 12.2 Hz, 1H), 2.36 – 2.02 (m, 7H), 1.99 – 1.83 (m, 1H).

(2S,5R)-2-(5-((((1r,3S)-3-aminocyclobutyl)amino)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate **(Compound 757)**. ESI-MS (EI^+, *m/z*): 389.2. ^1H NMR (300 MHz, D_2O, as formate salt) δ 8.30 (s, 1H), 4.76 (d, *J* = 6.5 Hz, 1H), 4.16 (br s, 1H), 4.01 (s, 2H), 3.44 (dt, *J* = 16.1, 8.0 Hz, 1H), 3.23 – 3.07 (m, 2H), 2.86 (d, *J* = 12.2 Hz, 1H), 2.65 – 2.47 (m, 2H), 2.33 – 2.03 (m, 3H), 1.98 – 1.76 (m, 3H)

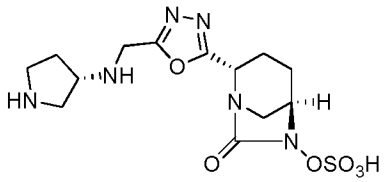
***Example 58**: Synthesis of (2S,5R)-7-oxo-2-(5-(((R)-pyrrolidin-3-ylamino)methyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 766)**

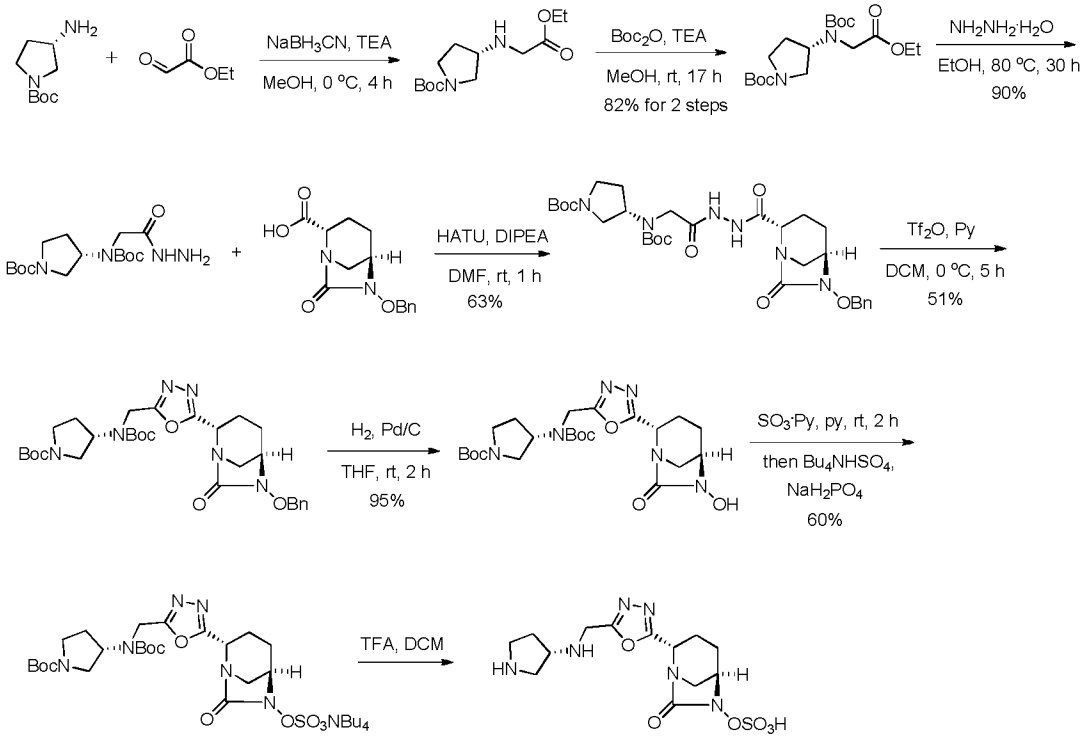




ESI-MS (EI$^+$, *m/z*): 389.1. ^{1}H NMR (300 MHz, D_2O) δ 4.77 (d, *J* = 6.5 Hz, 1H), 4.17 (br s, 1H), 4.03 (s, 2H), 3.60 – 3.45 (m, 1H), 3.36 (dd, *J* = 12.5, 6.0 Hz, 2H), 3.29 – 3.12 (m, 2H), 3.06 (dd, *J* = 12.2, 4.4 Hz, 1H), 2.89 (d, *J* = 12.2 Hz, 1H), 2.32 – 2.07 (m, 5H), 1.99 – 1.75 (m, 1H).

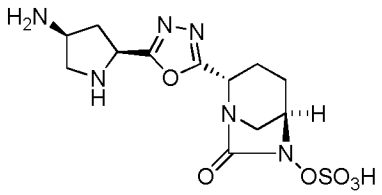
***Example 59**: Synthesis of (2S,5R)-7-oxo-2-(5-(((S)-pyrrolidin-3-ylamino)methyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 765**)*

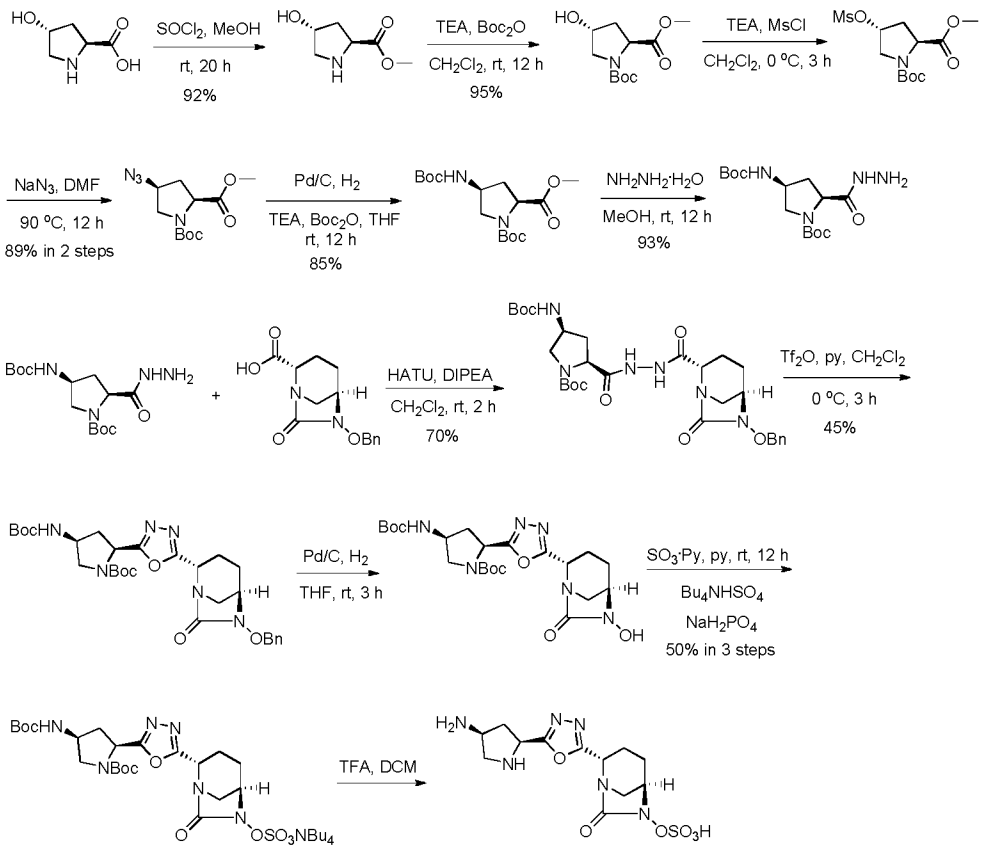




ESI-MS (EI$^+$, *m/z*): 389.2. ^{1}H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 6.5 Hz, 1H), 4.12 (br s, 1H), 3.98 (s, 2H), 3.54 – 3.41 (m, 1H), 3.39 – 3.26 (m, 2H), 3.27 – 3.06 (m, 2H), 3.01 (dd, *J* = 12.3, 5.1 Hz, 1H), 2.84 (d, *J* = 12.3 Hz, 1H), 2.29 – 1.97 (m, 4H), 1.98 – 1.61 (m, 2H).

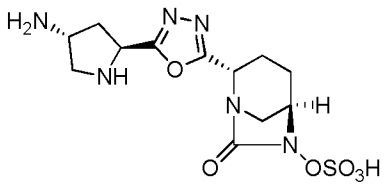
***Example 60**: Synthesis of (2S,5R)-2-(5-((2S,4S)-4-aminopyrrolidin-2-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 760**)**

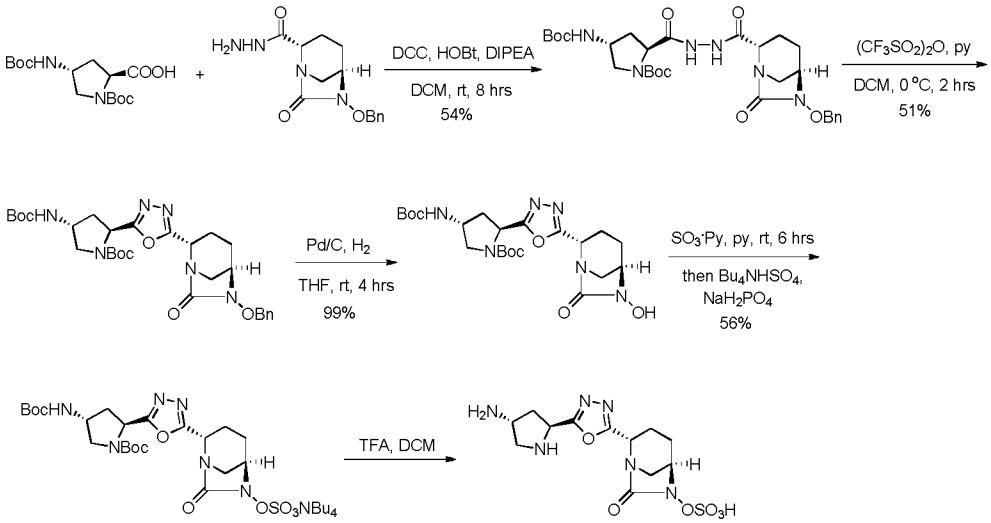




ESI-MS (EI$^+$, *m/z*): 375.2. ^{1}H NMR (300 MHz, D_2O) δ 4.76 (d, *J* = 6.7 Hz, 1H), 4.65 – 4.55 (m, 1H), 4.18 (br s, 1H), 3.93 – 3.80 (m, 1H), 3.40 – 3.28 (m, 1H), 3.24 – 3.13 (m, 1H), 2.96 – 2.83 (m, 2H), 2.75 (dd, *J* = 14.6, 7.9 Hz, 1H), 2.34 – 1.82 (m, 5H).

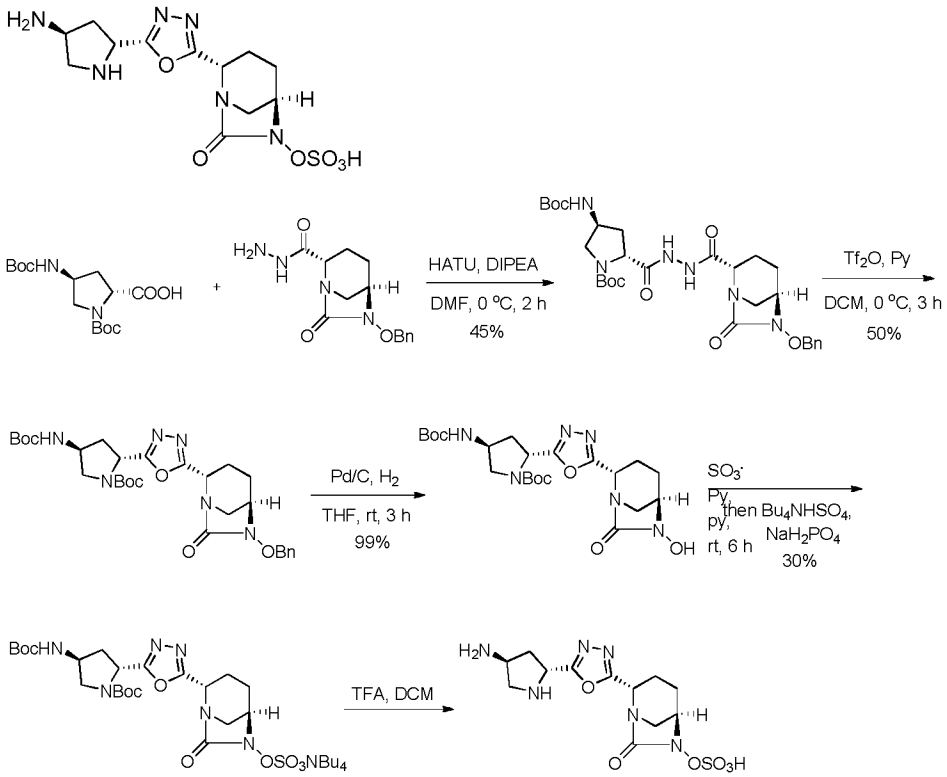
***Example 61**: Synthesis of (2S,5R)-2-(5-((2S,4R)-4-aminopyrrolidin-2-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 762**)**





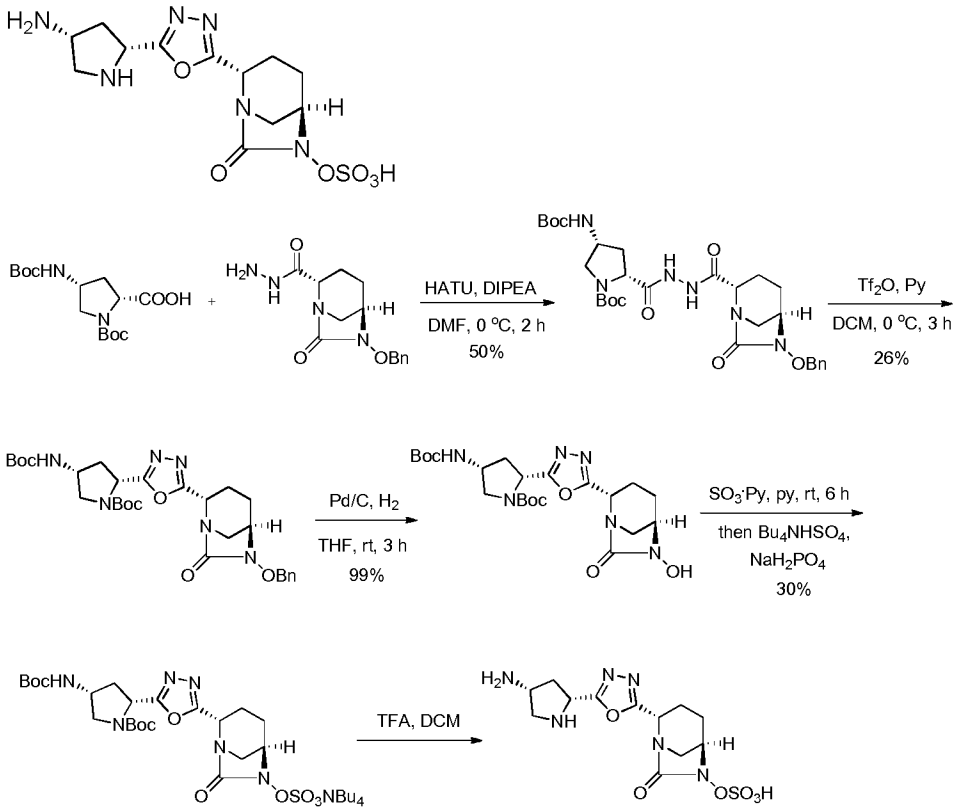
ESI-MS (EI^+, *m/z*): 375.3.

***Example 62**: Synthesis of (2S,5R)-2-(5-((2R,4S)-4-aminopyrrolidin-2-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 763**)*



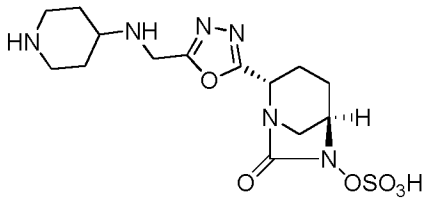
ESI-MS (EI^+, *m/z*): 375.3.

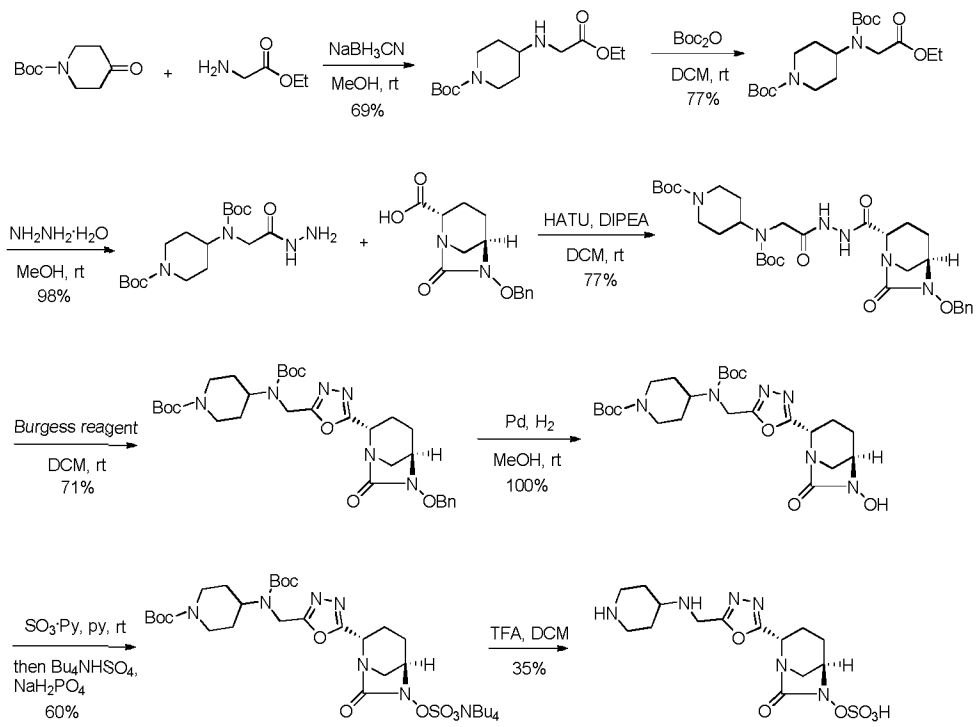
***Example 63**: Synthesis of (2S,5R)-2-(5-((2R,4R)-4-aminopyrrolidin-2-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 761**)*



ESI-MS (EI$^+$, *m/z*): 375.2. ^{1}H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 6.5 Hz, 1H), 4.59 (t, *J* = 7.7 Hz, 1H), 4.16 (br s, 1H), 3.92 – 3.78 (m, 1H), 3.32 (dd, *J* = 11.9, 7.2 Hz, 1H), 3.22 – 3.09 (m, 1H), 2.96 – 2.84 (m, 2H), 2.73 (dt, *J* = 15.8, 8.3 Hz, 1H), 2.33 – 1.76 (m, 5H).

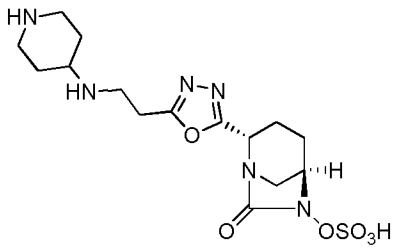
***Example 64**: Synthesis of (2S,5R)-7-oxo-2-(5-((piperidin-4-ylamino)methyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 769**)

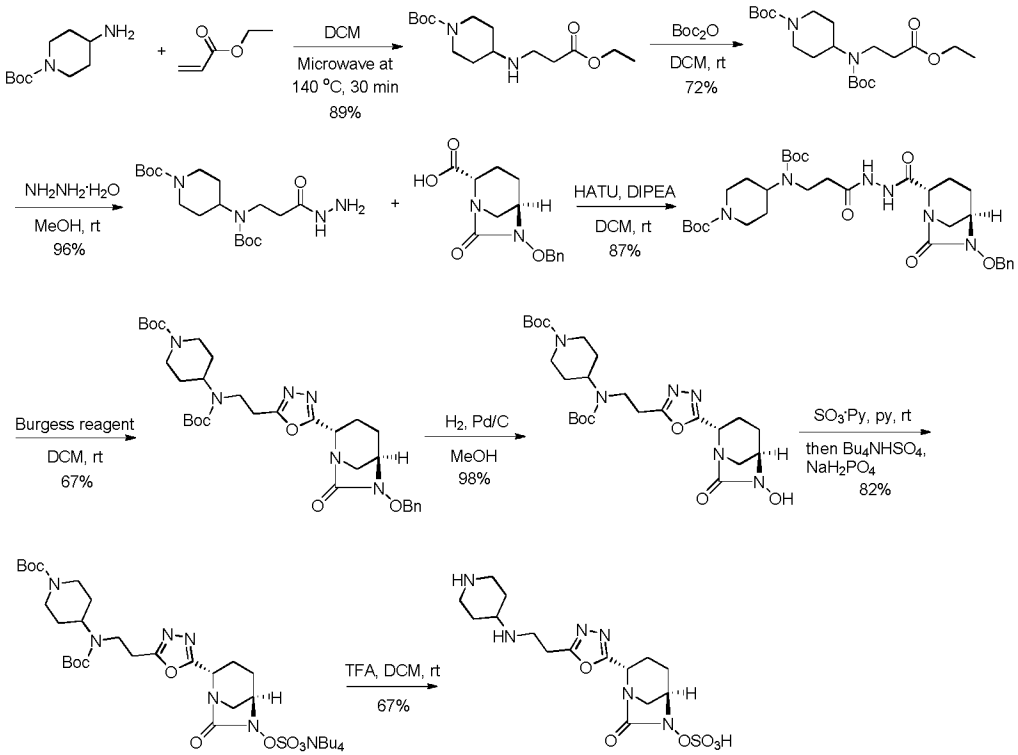




ESI-MS (EI$^+$, *m/z*): 403.1. ^{1}H NMR (300 MHz, D_2O) δ 4.81 (d, *J* = 6.5 Hz, 1H), 4.40 (s, 2H), 4.19 (br s, 1H), 3.55 – 3.41 (m, 2H), 3.34 – 3.23 (m, 1H), 3.20 (br d, *J* = 13.2 Hz, 1H), 3.01 – 2.94 (m, 2H), 2.91 (d, *J* = 12.3 Hz, 1H), 2.38 – 2.07 (m, 5H), 2.03 – 1.85 (m, 1H), 1.79 – 1.58 (m, 2H).

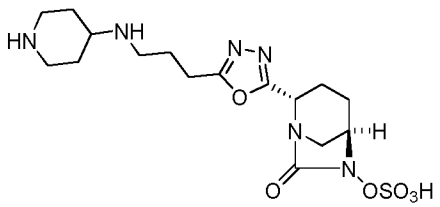
***Example 65**: Synthesis of (2S,5R)-7-oxo-2-(5-(2-(piperidin-4-ylamino)ethyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* **(Compound 770)**

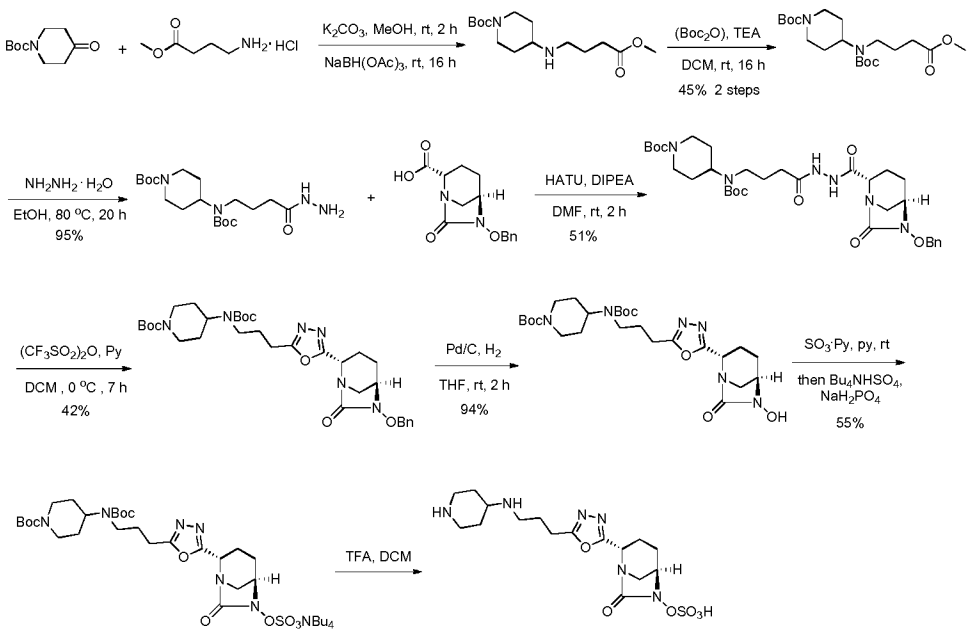




ESI-MS (EI^+, *m/z*): 417.2. ^1H NMR (300 MHz, D_2O) δ 4.79 (d, *J* = 6.9 Hz, 1H), 4.20 (br s, 1H), 3.61 – 3.51 (m, 5H), 3.38 (t, *J* = 7.0 Hz, 2H), 3.21 (br d, *J* = 12.4 Hz, 1H), 3.11 – 3.01 (m, 2H), 2.97 (d, *J* = 12.3 Hz, 1H), 2.39 – 2.10 (m, 5H), 2.01 – 1.76 (m, 3H).

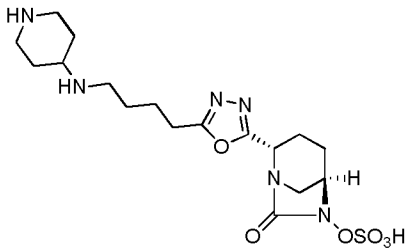
***Example 66**: Synthesis of (2S,5R)-7-oxo-2-(5-(3-(piperidin-4-ylamino)propyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 771**)**

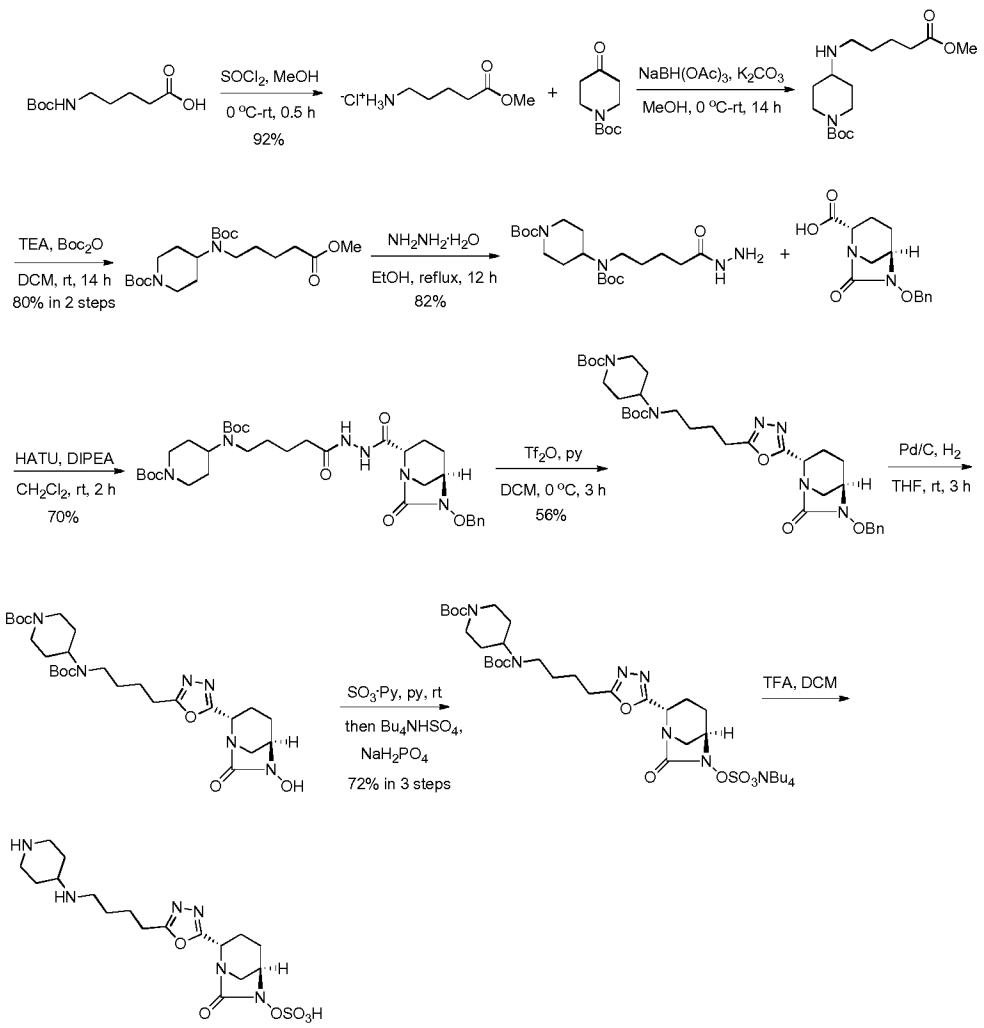




ESI-MS (EI$^+$, *m/z*): 431.1. ^{1}H NMR (300 MHz, D_2O, as formate salt) δ 8.34 (s, 1H), 4.74 (d, *J* = 6.5 Hz, 1H), 4.17 (br s, 1H), 3.71 – 3.21 (m, 3H), 3.23 – 2.69 (m, 8H), 2.34 – 2.06 (m, 7H), 2.02 – 1.59 (m, 3H).

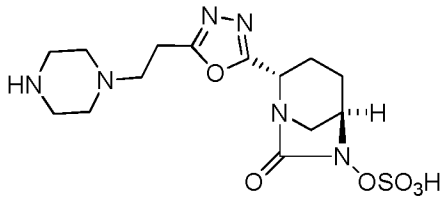
***Example 67**: Synthesis of (2S,5R)-7-oxo-2-(5-(4-(piperidin-4-ylamino)butyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 772**)**

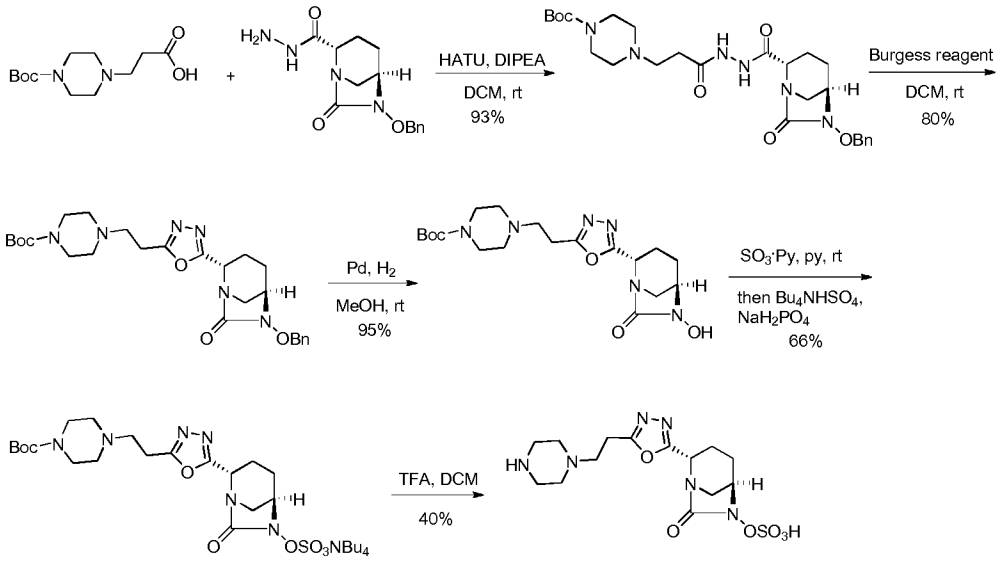




ESI-MS (EI^+, *m/z*): 445.3. ^1H NMR (300 MHz, D_2O, as formate salt) δ 8.28 (s, 1H), 4.72 (d, *J* = 6.5 Hz, 1H), 4.12 (br s, 1H), 3.50 – 3.24 (m, 3H), 3.11 (d, *J* = 13.6 Hz, 1H), 3.06 – 2.72 (m, 7H), 2.35 – 2.00 (m, 5H), 1.97 – 1.51 (m, 7H).

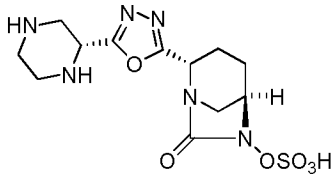
Example 68 *: Synthesis of (2S,5R)-7-oxo-2-(5-(2-(piperazin-1-yl)ethyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 776)***

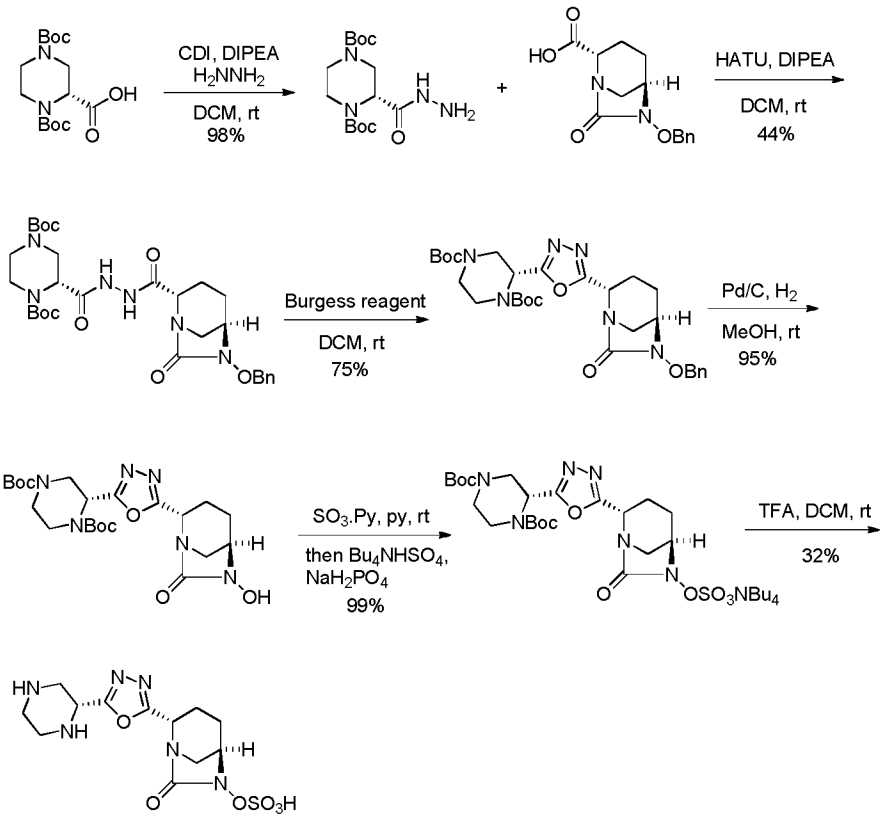




ESI-MS (EI^+, *m/z*): 403.2. ^{1}H NMR (300 MHz, D_2O) δ 4.75 (d, *J* = 6.4 Hz, 1H), 4.16 (br s, 1H), 3.21 – 3.02 (m, 6H), 2.96 – 2.83 (m, 4H), 2.71 (br s, 4H), 2.32 – 2.03 (m, 3H), 1.96-1.84 (m, 1H).

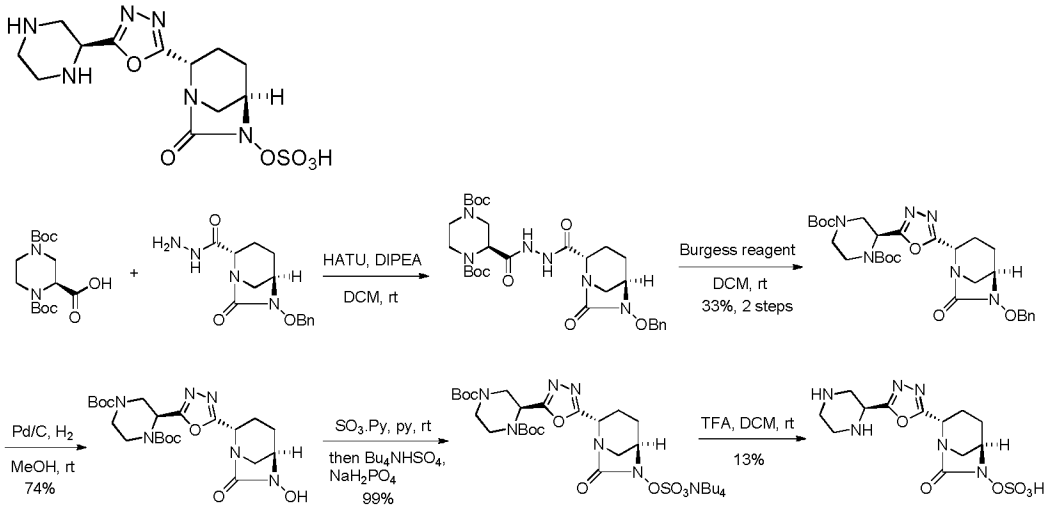
Example 69*: Syntehsis of (2S,5R)-7-oxo-2-(5-((R)-piperazin-2-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 779)***





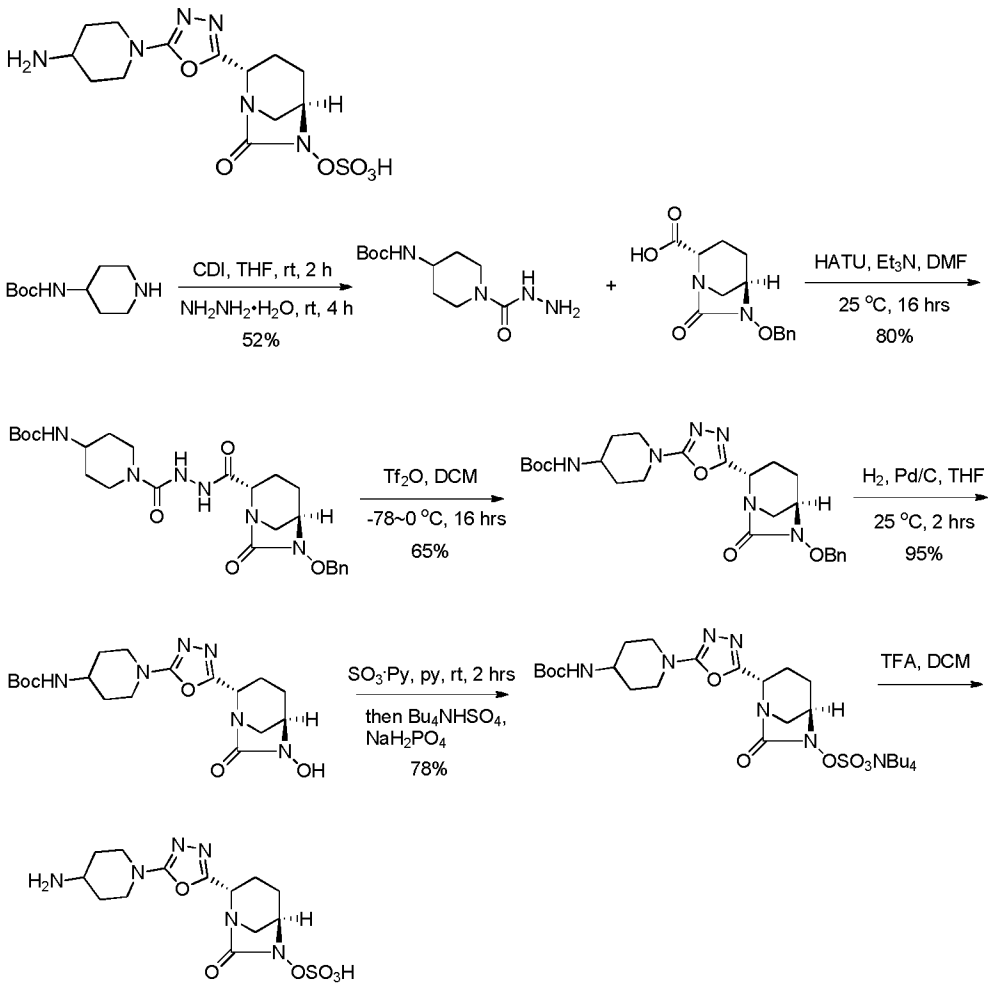
ESI-MS (EI$^+$, *m/z*): 375.3. ^{1}H NMR (300 MHz, D_2O) δ 4.81 (d, *J* = 6.5 Hz, 1H), 4.57 (dd, *J* = 8.8, 3.5 Hz, 1H), 4.19 (br s, 1H), 3.65 (dd, *J* = 13.0, 3.4 Hz, 1H), 3.46 – 2.98 (m, 6H), 2.92 (d, *J* = 12.4 Hz, 1H), 2.34 – 2.05 (m, 3H), 2.02 – 1.82 (m, 1H).

Example 70**: Syntehsis of (2S,5R)-7-oxo-2-(5-((S)-piperazin-2-yl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 778)



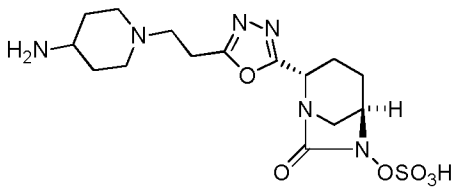
ESI-MS (EI$^+$, *m/z*): 375.3.

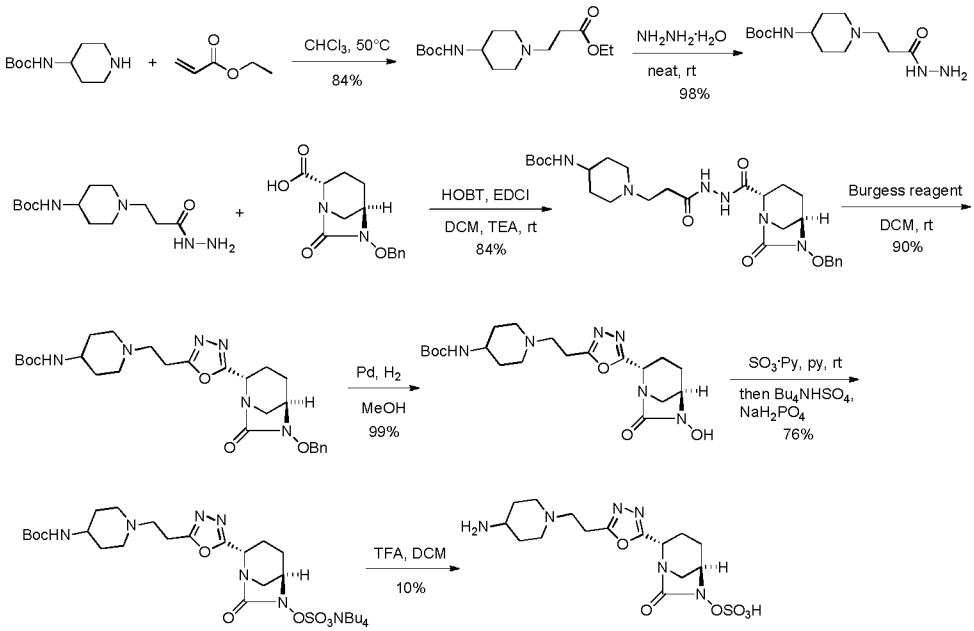
***Example 71**: Synthesis of (2S,5R)-2-(5-(4-aminopiperidin-1-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 773**)*



ESI-MS (EI^+, *m/z*): 389.1. ^{1}H NMR (300 MHz, D_2O) δ 4.61 (d, *J* = 6.4 Hz, 1H), 4.17 (br s, 1H), 3.96 (d, *J* = 13.5 Hz, 2H), 3.52 – 3.36 (m, 1H), 3.26 – 3.06 (m, 3H), 2.97 (d, *J* = 12.2 Hz, 1H), 2.31 – 1.83 (m, 6H), 1.80 – 1.45 (m, 2H).

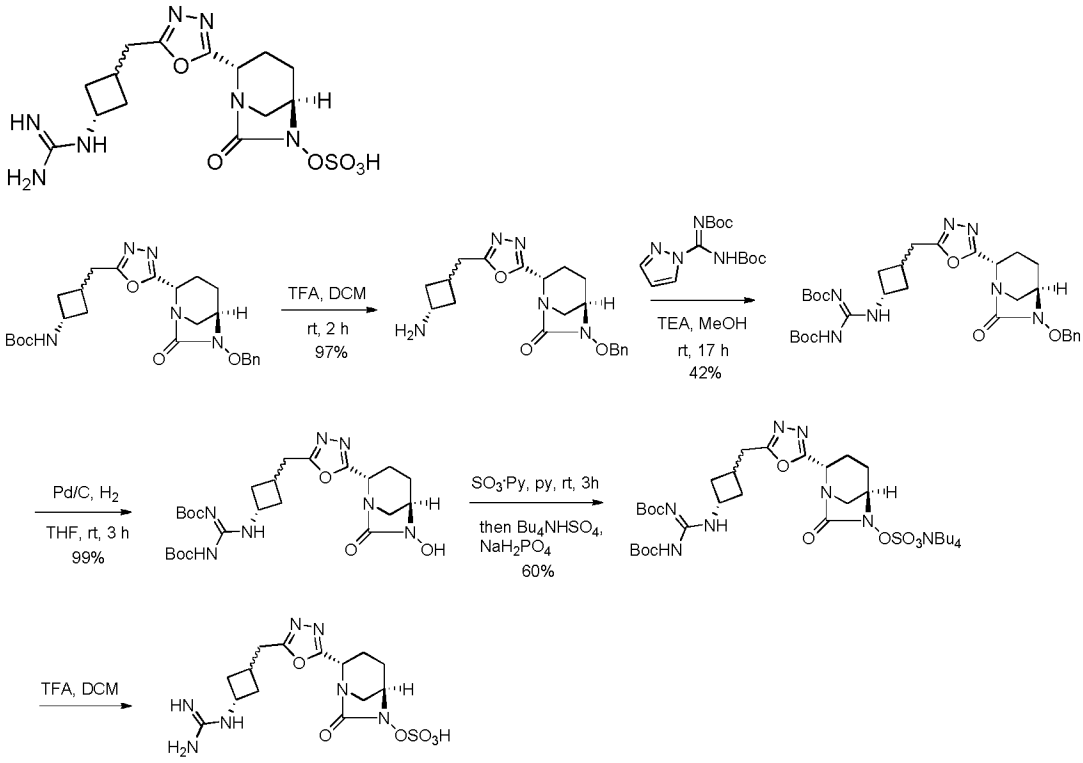
***Example 72**: Synthesis of (2S,5R)-2-(5-(2-(4-aminopiperidin-1-yl)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 775**)*





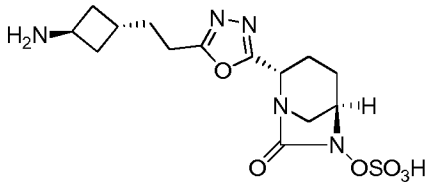
ESI-MS (EI$^+$, *m/z*): 417.2. ^{1}H NMR (300 MHz, D_2O, as formate salt) δ 8.31 (s, 1H), 4.74 (d, *J* = 6.1 Hz, 1H), 4.16 (br s, 1H), 3.78 – 3.55 (m, 4H), 3.55 – 3.32 (m, 3H), 3.25 – 3.04 (m, 3H), 2.90 (d, *J* = 12.2 Hz, 1H), 2.32 – 2.04 (m, 5H), 1.97 – 1.75 (m, 3H).

***Example 73**: Synthesis of (2S,5R)-2-(5-((3-guanidinocyclobutyl)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 752**)**

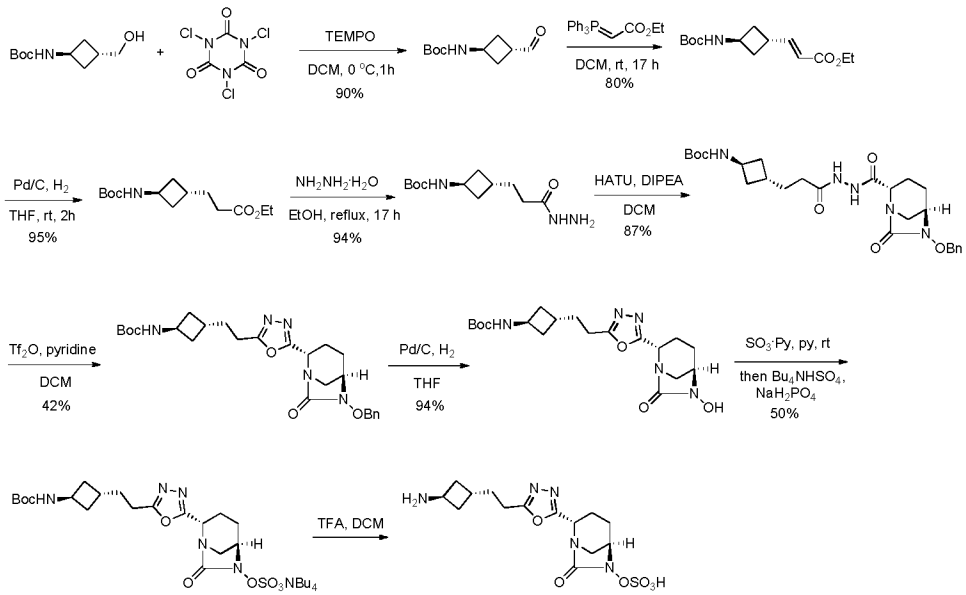


ESI-MS (EI$^+$, *m/z*): 416.2.

***Example 74**: Synthesis of (2S,5R)-2-(5-(2-((1r,3R)-3-aminocyclobutyl)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 753**)*

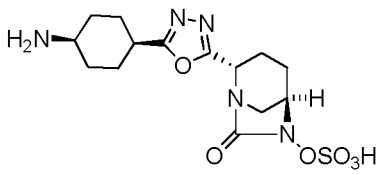


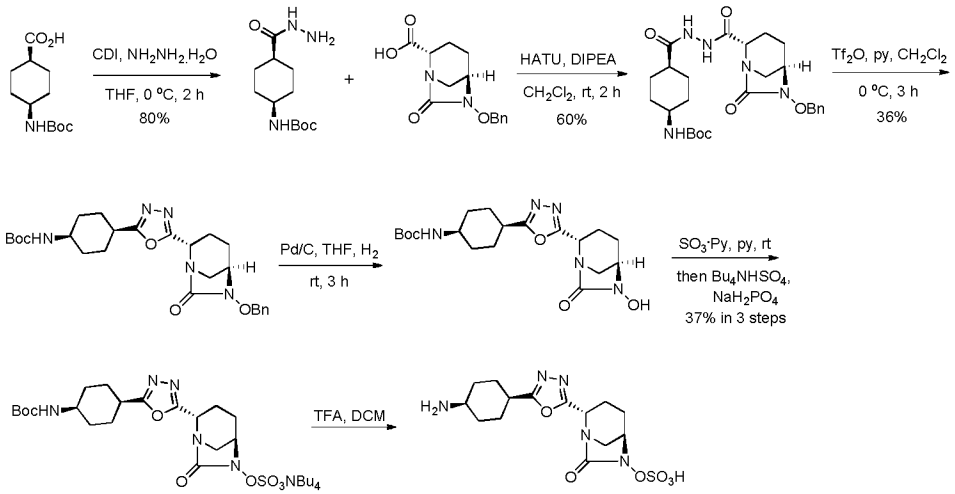
5



ESI-MS (EI$^+$, *m/z*): 388.3. ^{1}H NMR (300 MHz, D_2O) δ 4.74 (d, *J* = 6.5 Hz, 1H), 4.15 (br s, 1H), 3.81 – 3.69 (m, 1H), 3.20 – 3.08 (m, 1H), 2.92 – 2.72 (m, 3H), 2.43 – 1.75 (m, 11H).

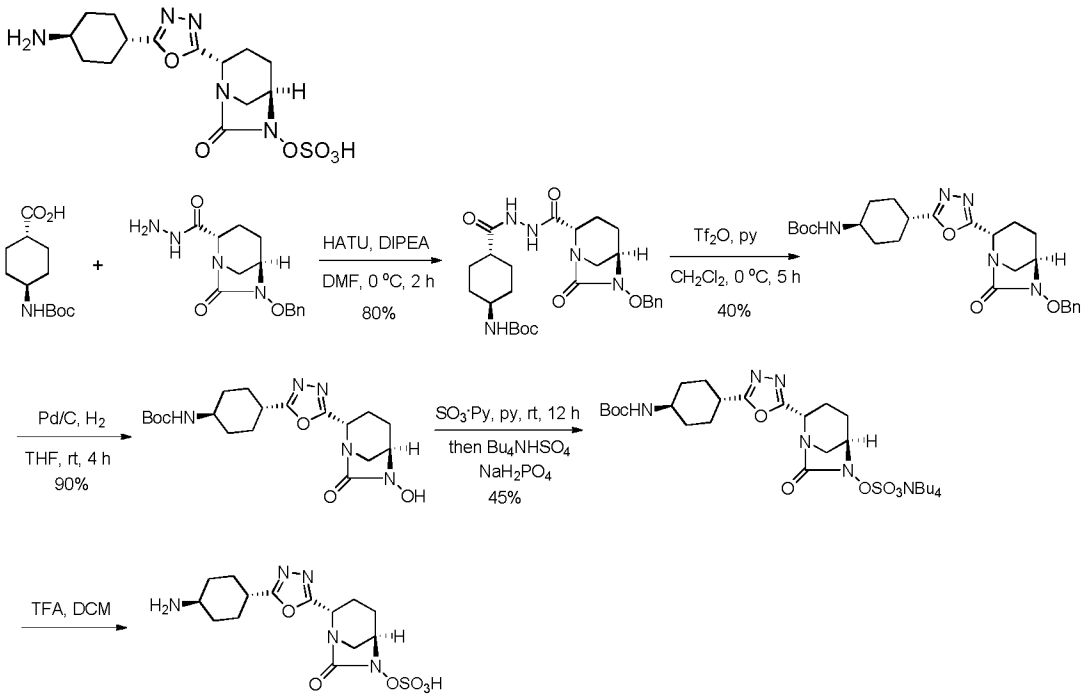
10 ***Example 75**: Synthesis of (2S,5R)-2-(5-((1s,4R)-4-aminocyclohexyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 780**)*





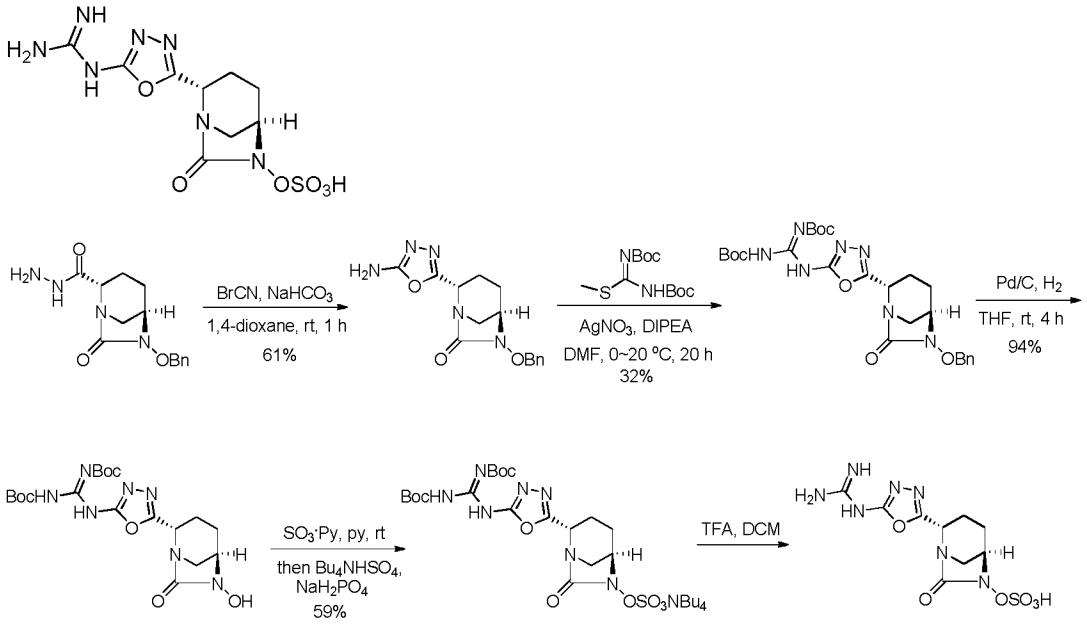
ESI-MS (EI$^+$, *m/z*): 388.2.

***Example 76**: Synthesis of (2S,5R)-2-(5-((1r,4S)-4-aminocyclohexyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 781**)*



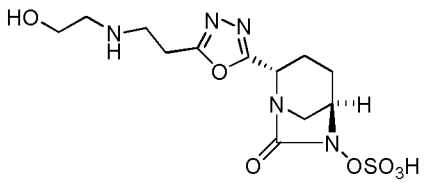
ESI-MS (EI$^+$, *m/z*): 388.2. ^{1}H NMR (300 MHz, D_2O) δ 4.72 (d, *J* = 6.6 Hz, 1H), 4.15 (br s, 1H), 3.24 – 3.03 (m, 3H), 3.01 – 2.89 (m, 1H), 2.86 (d, *J* = 12.3 Hz, 1H), 2.30 – 1.98 (m, 4H), 1.98 – 1.79 (m, 1H), 1.69 – 1.37 (m, 4H), 1.32 – 1.10 (m, 2H).

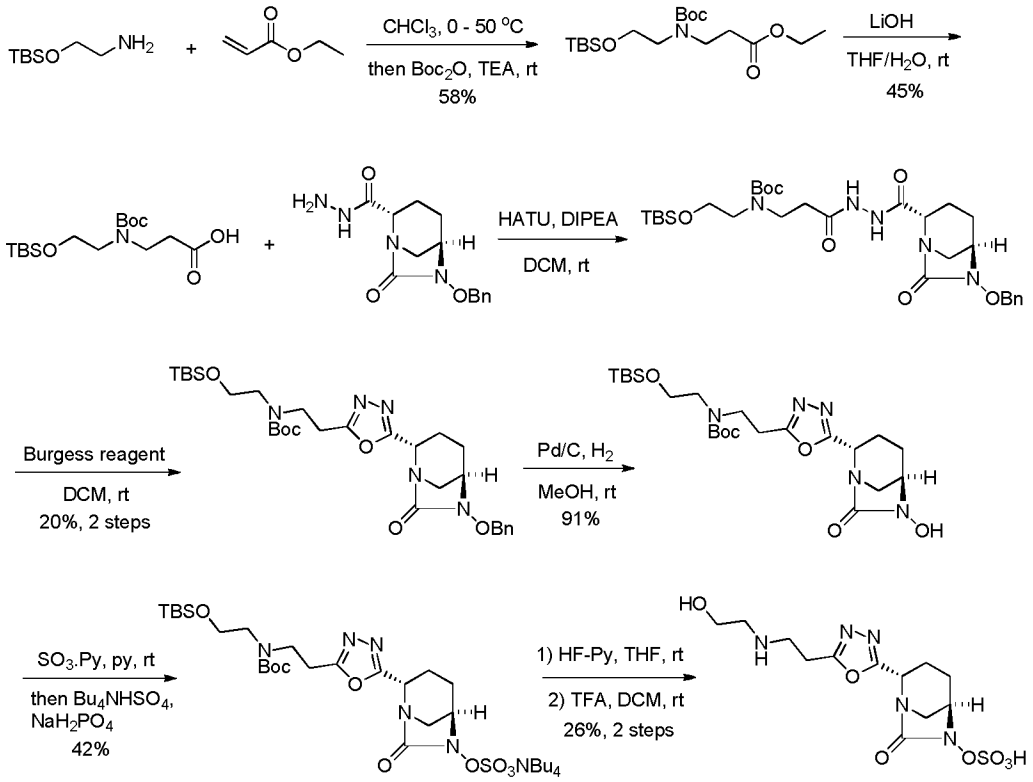
Example 77**: Synthesis of (2S,5R)-2-(5-guanidino-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate **(Compound 738)



ESI-MS (EI^+, *m/z*): 348.1. ^1H NMR (300 MHz, D_2O) δ 4.60 (d, *J* = 6.6 Hz, 1H), 4.15 (br s, 1H), 3.20 – 3.10 (m, 1H), 2.97 (d, *J* = 12.3 Hz, 1H), 2.27 – 1.85 (m, 4H).

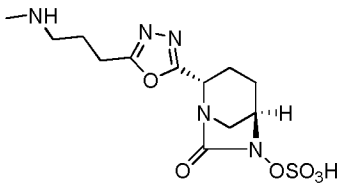
Example 78**: Synthesis of (2S,5R)-2-(5-(2-((2-hydroxyethyl)amino)ethyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate **(Compound 736)

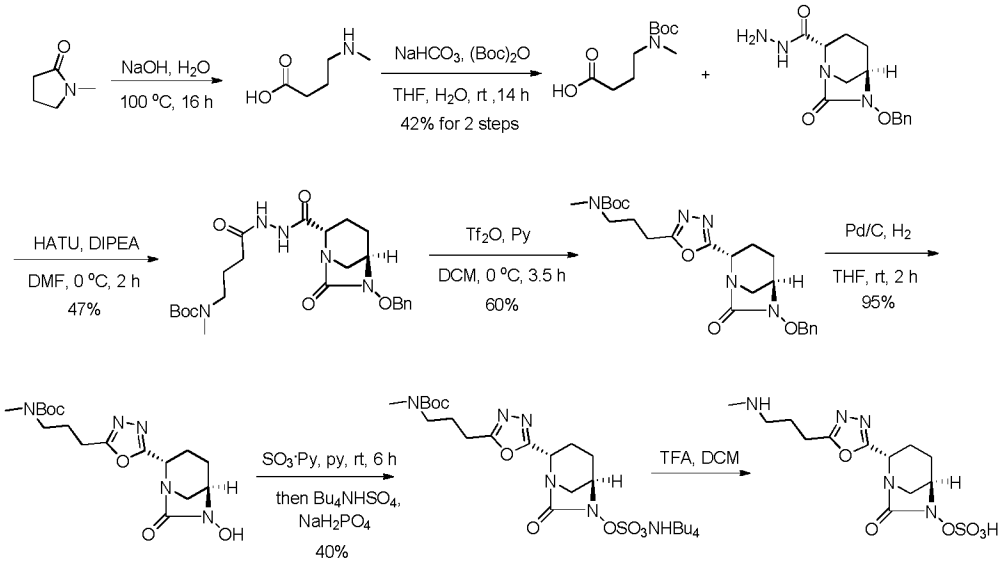




ESI-MS (EI^+, *m/z*): 378.2.

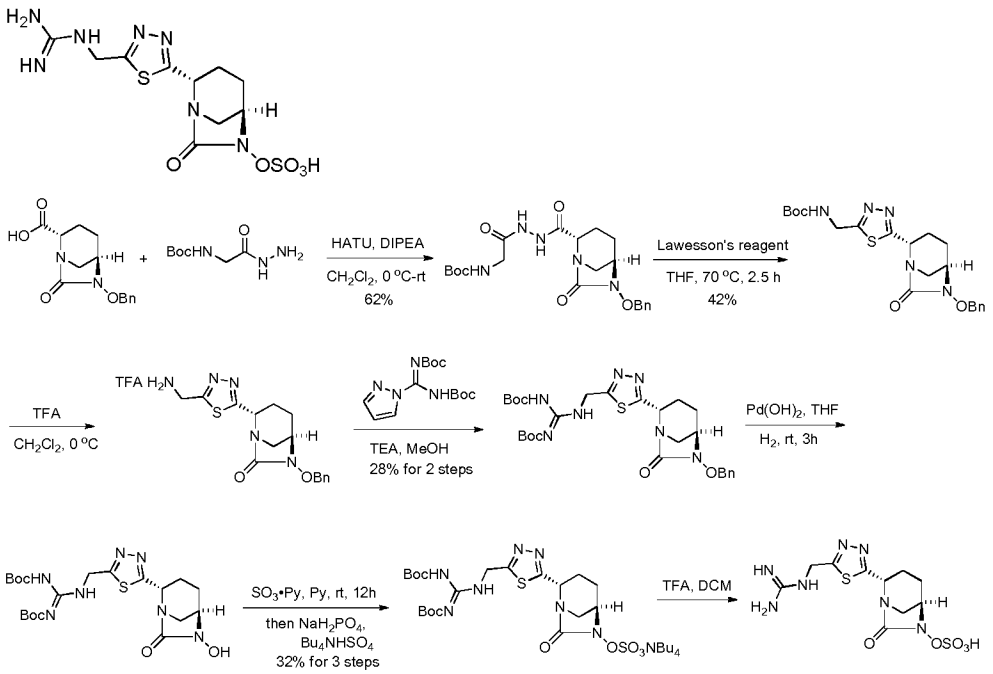
***Example 79**: (2S,5R)-2-(5-(3-(methylamino)propyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 734**)*





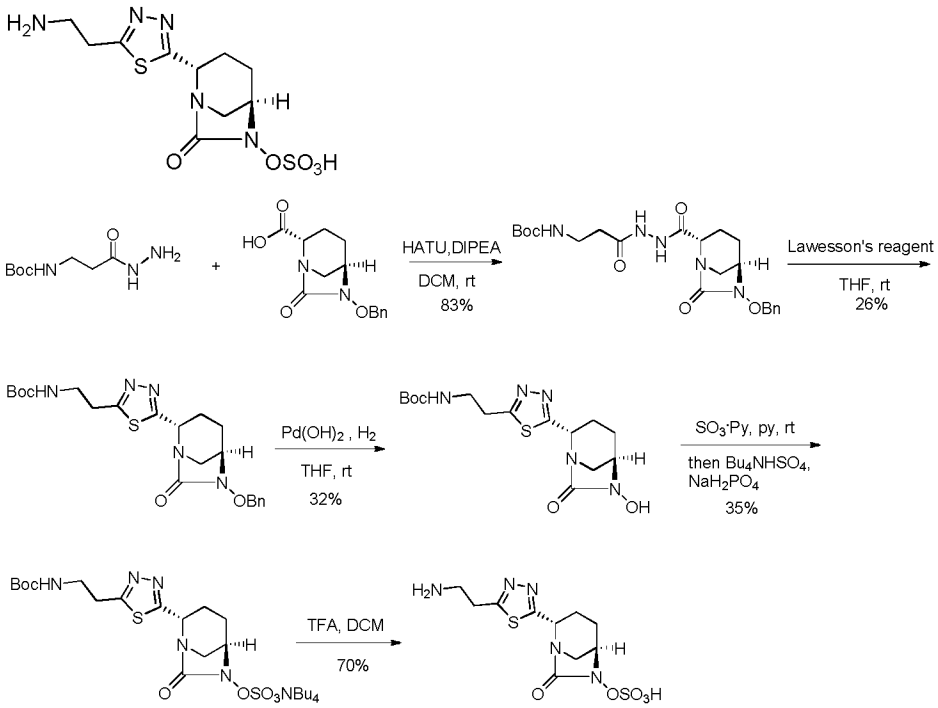
ESI-MS (EI^+, *m/z*): 362.2. ^1H NMR (300 MHz, D_2O) δ 4.73 (d, *J* = 6.5 Hz, 1H), 4.15 (br s, 1H), 3.15 (br d, *J* = 12.1 Hz, 1H), 3.08 – 2.99 (m, 2H), 2.96 (t, *J* = 7.5 Hz, 2H), 2.87 (d, *J* = 12.3 Hz, 1H), 2.61 (s, 3H), 2.32 – 2.02 (m, 5H), 1.99 – 1.78 (m, 1H).

Example 80**: Synthesis of (2S,5R)-2-(5-(guanidinomethyl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 721)



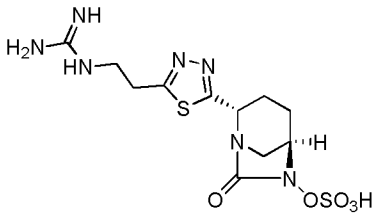
ESI-MS (EI^+, *m/z*): 378.1.

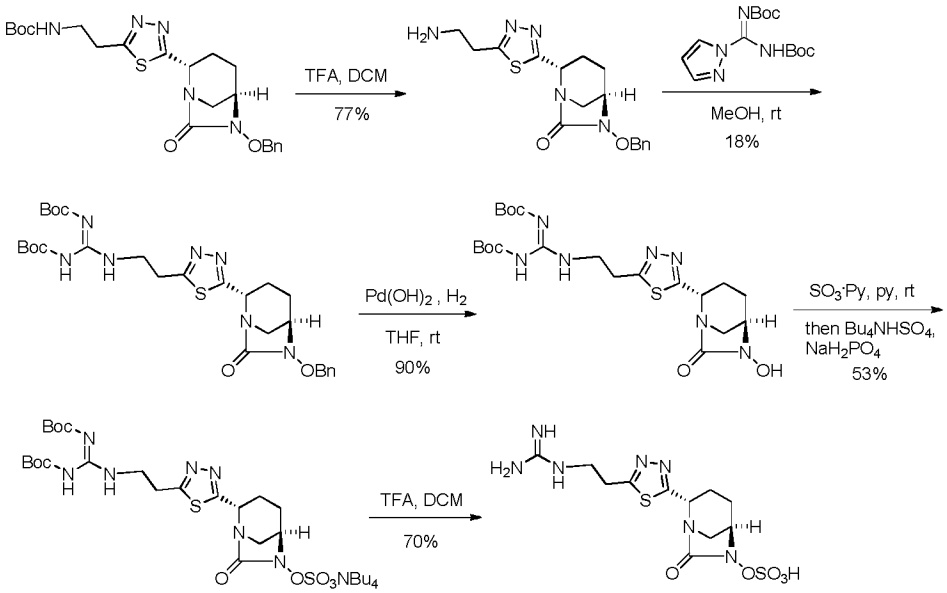
Example 81**: Synthesis of (2S,5R)-2-(5-(2-aminoethyl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 718)



ESI-MS (EI$^+$, *m/z*): 350.1. ^{1}H NMR (300 MHz, D_2O) δ 4.89 (d, *J* = 6.3 Hz, 1H), 4.14 (br s, 1H), 3.50 – 3.35 (m, 4H), 3.14 (br d, *J* = 12.2 Hz, 1H), 2.90 (d, *J* = 12.2 Hz, 1H), 2.50 - 2.38 (m, 1H), 2.20 – 2.05 (m, 2H), 1.90 – 1.80 (m, 1H).

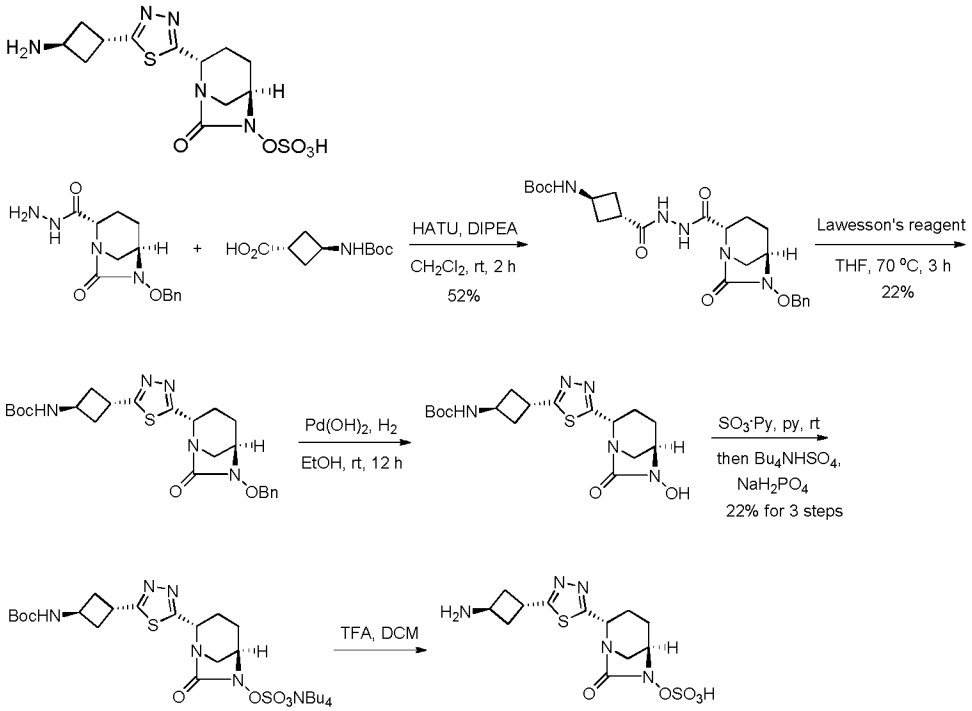
***Example 82**: Synthesis of (2S,5R)-2-(5-(2-guanidinoethyl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 794**)*





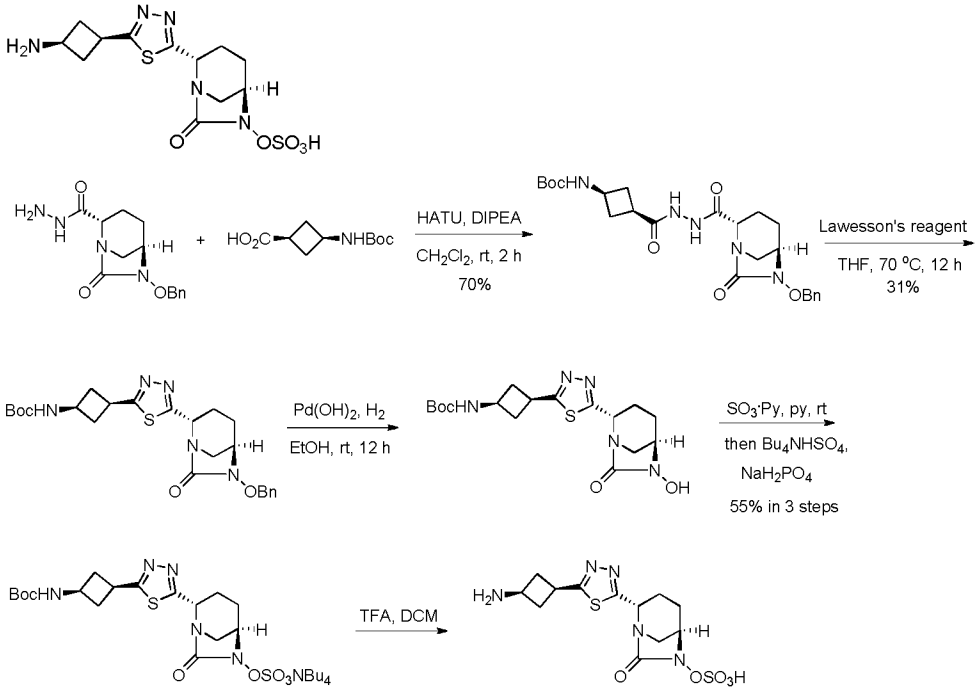
ESI-MS (EI^+, *m/z*): 392.1. ^1H NMR (300 MHz, D_2O) δ 4.89 (d, *J* = 6.7 Hz, 1H), 4.14 (br s, 1H), 3.57 (t, *J* = 6.3 Hz, 2H), 3.34 (t, *J* = 6.3 Hz, 2H), 3.14 (br d, *J* = 12.2 Hz, 1H), 2.84 (d, *J* = 12.2 Hz, 1H), 2.46 - 2.40 (m, 1H), 2.20 – 2.05 (m, 2H), 1.92 - 1.80 (m, 1H).

***Example 83**: Synthesis of (2S,5R)-2-(5-((1r,3S)-3-aminocyclobutyl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* (**Compound 783**)*



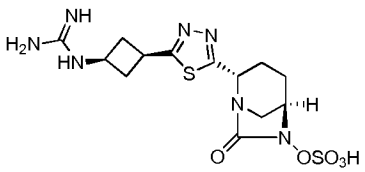
ESI-MS (EI$^+$, *m/z*): 376.3. ^{1}H NMR (300 MHz, D_2O) δ 4.90 (d, *J* = 6.6 Hz, 1H), 4.15 – 4.00 (m, 3H), 3.15 (br d, *J* = 12.2 Hz, 1H), 2.90 (d, *J* = 12.4 Hz, 1H), 2.74 - 2.69 (m, 4H), 2.48 - 2.40 (m, 1H), 2.19 - 2.10 (m, 2H), 1.93 - 1.82 (m, 1H).

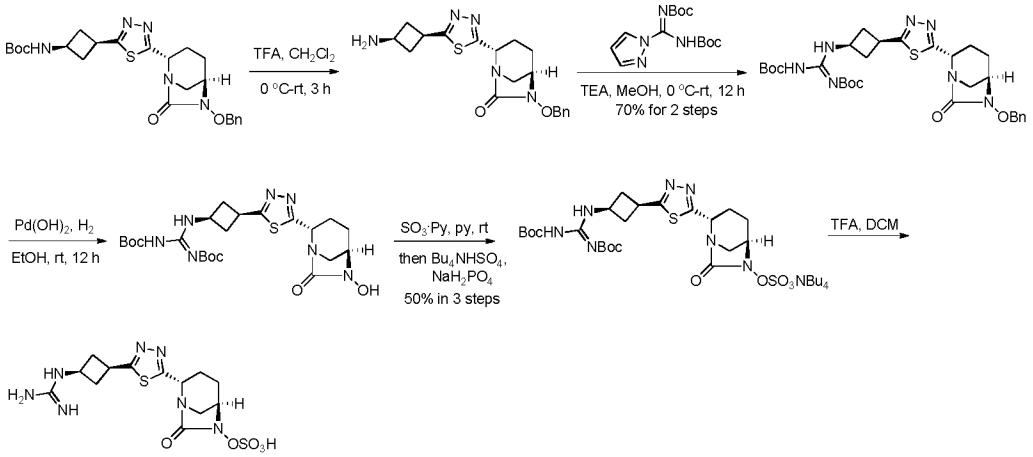
***Example 84**: Synthesis of (2S,5R)-2-(5-((1s,3R)-3-aminocyclobutyl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 795**)*



ESI-MS (EI$^+$, *m/z*): 376.0. ^{1}H NMR (300 MHz, D_2O with a few drops of DMSO-d6) δ 4.87 (d, *J* = 6.0 Hz, 1H), 4.14 (br s, 1H), 3.90 - 3.82 (m, 2H), 3.14 (d, *J* = 11.4 Hz, 1H), 2.92 - 2.89 (m, 3H), 2.55 – 2.37 (m, 3H), 2.20 - 2.14 (m, 2H), 1.93 - 1.88 (m, 1H).

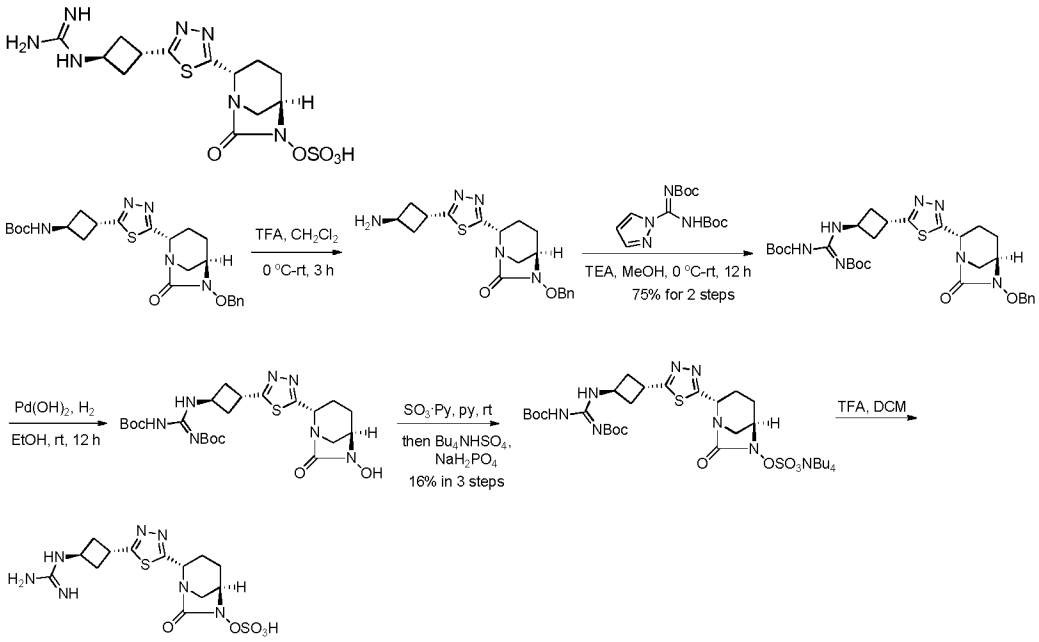
***Example 85**: Synthesis of (2S,5R)-2-(5-((1s,3R)-3-guanidinocyclobutyl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 784**)*





ESI-MS (EI$^+$, *m/z*): 418. ^{1}H NMR (300 MHz, DMSO-d6) δ 8.08 (br s, 1H), 7.13 (br s, 4H), 4.78 (d, *J* = 6.4 Hz, 1H), 4.09 - 4.01 (m, 2H), 3.70 - 3.62 (m, 1H), 2.95 - 2.88 (m, 2H), 2.70 (d, *J* = 11.9 Hz, 1H), 2.58 - 2.40 (m, 2H), 2.37 - 2.26 (m, 2H), 2.10 – 1.90 (m, 2H), 1.82 - 1.70 (m, 1H).

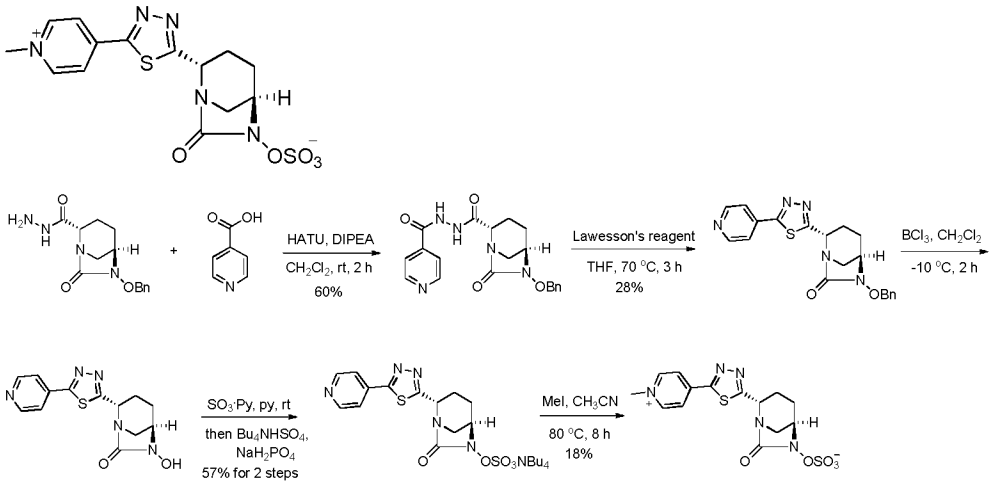
***Example 86**: Synthesis of (2S,5R)-2-(5-((1r,3S)-3-guanidinocyclobutyl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate (**Compound 785**)*



ESI-MS (EI$^+$, *m/z*): 418.4. ^{1}H NMR (300 MHz, D_2O) δ 4.87 (d, *J* = 14.3 Hz, 1H), 4.27 – 4.12 (m, 2H), 4.09 – 3.94 (m, 1H), 3.21 – 3.10 (m, 1H), 2.91 (d, *J* = 12.3 Hz, 1H), 2.78 – 2.52 (m, 4H), 2.50 – 2.38 (m, 1H), 2.22 – 2.04 (m, 2H), 1.96 – 1.81 (m, 1H).

***Example 87**: Synthesis of (2S,5R)-2-(5-(1-methylpyridin-1-ium-4-yl)-1,3,4-thiadiazol-2-yl)-7-*

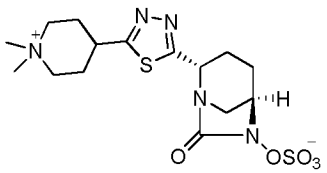
oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate ***(Compound 786)***



ESI-MS (EI⁻, *m/z*):. 396.0.

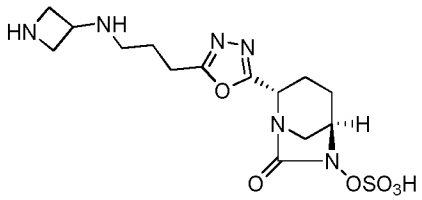
The compounds described in Examples 88-98 were prepared following similar chemistry and procedures of Examples 1-87.

Example 88*: Synthesis of (2S,5R)-2-(5-(1,1-dimethylpiperidin-1-ium-4-yl)-1,3,4-thiadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl sulfate* ***(Compound 796)***



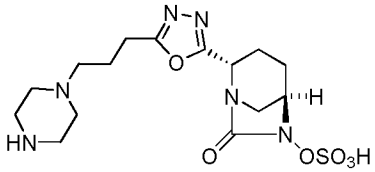
ESI-MS (EI⁻, *m/z*): 416.1.

Example 89*: Synthesis of (2S,5R)-2-(5-(3-(azetidin-3-ylamino)propyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 793)***



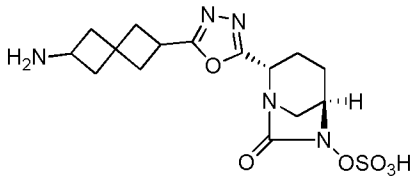
ESI-MS (EI⁺, *m/z*): 403.3.

Example 90*: Synthesis of (2S,5R)-7-oxo-2-(5-(3-(piperazin-1-yl)propyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 792)***



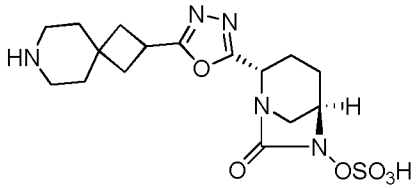
ESI-MS (EI$^+$, *m/z*): 417.2. ^{1}H NMR (300 MHz, D_2O) δ 4.73 (d, *J* = 7.6 Hz, 1H), 4.16 (br s, 1H), 3.51 – 3.35 (m, 4H), 3.28 (brs, 4H), 3.22 – 3.12 (m, 1H), 3.12 – 2.84 (m, 5H), 2.34 – 2.03 (m, 5H), 2.02 – 1.82 (m, 1H).

Example 91*: Synthesis of (2S,5R)-2-(5-(6-aminospiro[3.3]heptan-2-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 787)***



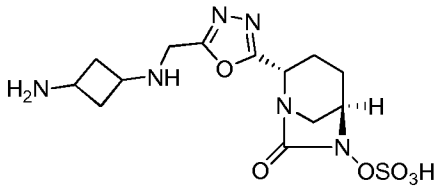
ESI-MS (EI$^+$, *m/z*): 400.0.

Example 92*: Synthesis of (2S,5R)-2-(5-(7-azaspiro[3.5]nonan-2-yl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 788)***



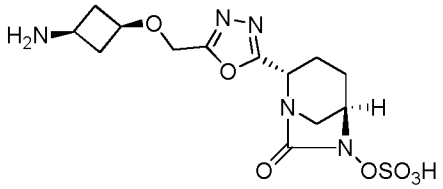
ESI-MS (EI$^+$, *m/z*): 414.0.

Example 93*: Synthesis of (2S,5R)-2-(5-(((3-aminocyclobutyl)amino)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 755)***



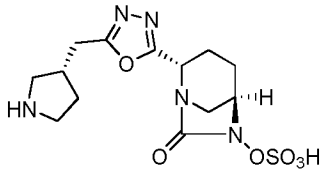
ESI-MS (EI$^+$, *m/z*): 389.4

Example 94*: Synthesis of (2S,5R)-2-(5-(((1s,3R)-3-aminocyclobutoxy)methyl)-1,3,4-oxadiazol-2-yl)-7-oxo-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 789)***



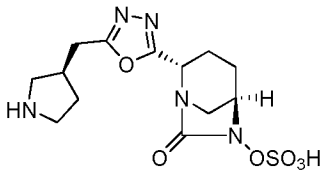
ESI-MS (EI^+, *m/z*): 390.1.

Example 95:*Synthesis of (2S,5R)-7-oxo-2-(5-((S)-pyrrolidin-3-ylmethyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 790)***



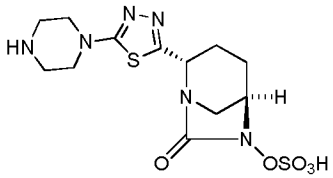
ESI-MS (EI^+, *m/z*): 374.2.

Example 96: *Synthesis of (2S,5R)-7-oxo-2-(5-((R)-pyrrolidin-3-ylmethyl)-1,3,4-oxadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 791)***



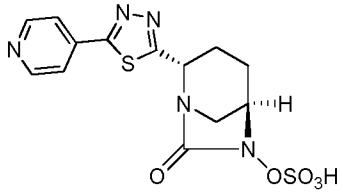
ESI-MS (EI^+, *m/z*): 374.3.

Example 97: *Synthesis of (2S,5R)-7-oxo-2-(5-(piperazin-1-yl)-1,3,4-thiadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 797)***



ESI-MS (EI^+, *m/z*): 391.1.

Example 98: *Synthesis of (2S,5R)-7-oxo-2-(5-(pyridin-4-yl)-1,3,4-thiadiazol-2-yl)-1,6-diazabicyclo[3.2.1]octan-6-yl hydrogen sulfate* ***(Compound 798)***



ESI-MS (EI, *m/z*):. 382.0.

Example 99: *Construction of Isogenic β-lactamase strains*

A set of β-lactamase expressing isogenic *E. coli* strains was constructed by cloning a β-lactamase gene into a customized derivative of pBR322 (GenBank Accession Number J01749) and transforming the engineered plasmids into *E. coli*. The *Nde*I restriction site within the plasmid backbone of pBR322 was removed to generate pBR322 Δ*Nde*I. The pBR322 Δ*Nde*I vector itself, minus the *bla*TEM-1 gene, was amplified using two primers: (1) pBR-Pbla 5'-cgcatatgactcttccttttcaatattattg-3, SEQ ID 1, a primer with an engineered *Nde*I restriction site at the 3' end of the *bla*TEM-1 promoter and (2) pBR-vec-1 5'-gcggatccctgtcagaccaagtttactc-3', SEQ ID 2, a primer with an engineered *Bam*HI restriction site at the 3' end of the *bla*TEM-1 open reading frame. The chloramphenicol resistance gene, *cat*, was generated by PCR amplification from pKD3 (GenBank Accession Number AY048742) using primers with an engineered *Nde*I restriction site at the 5' end (Pbla-cat 5'-gccatatgatggagaaaaaaatcactgg-3', SEQ ID 3) and an engineered *Bam*HI restriction site at the 3' end (Vec-1-cat 5'-cgggatccctagagaataggaacttcgg-3', SEQ ID 4)of the resistance gene. The two PCR products, pBR322 Δ*Nde*I and *cat* were ligated together generating pBR-CBST (pBR322 Δ*NdeI* Δ*TEM-1*::*cat* Seq. ID 5) which retains both the pBR322 tetracycline resistance cassette, *tetA*, and the plasmid origin of replication but the *bla*TEM-1 gene was replaced by the *cat* gene.

Using this engineering strategy a number of plasmids producing β-lactamase genes from different classes (see below) were generated using synthetic genes with an engineered *Nde*I restriction site at the 5' end and *Bam*HI restriction site at the 3' end of each gene (GenScript). Both the synthetic β-lactamase genes and *cat* gene were ligated into the *Nde*I/*Bam*HI sites of the pBR322 Δ*Nde*I PCR product and transformed into electrocompetent *E. coli* ElectroMax DH10B (Invitrogen/Life Technologies). *E. coli* DH10B harboring the recombinant plasmids were selected on LB agar (supplemented with 25 μg/mL tetracycline) and single isolated colonies were then inoculated into 5 mL LB media (supplemented with 25 μg/mL tetracycline), and incubated at 37°C with aeration (250 rpm) for 18 hrs. The cultures were frozen back at -80°C in 20% glycerol. The DNA sequence of the cloned β-

lactamase genes was confirmed. The β-lactamase gene expression in the recombinant *E. coli* strains was driven by the *bla*TEM-1 promoter in the pBR-CBST plasmid and was characterized by MIC profiling of the *E. coli* recombinant strains against comparator β-lactam/BLI combinations in broth microdilution assay.

β-Lactamase Expressing Strain	Name & SEQ. ID of plasmids producing β-Lactamase	β-Lactamase Class	Species Origin of β-Lactamase Gene	GenBank Accession Number of β-Lactamase Gene Sequence
KPC-2	pBR-CBST-KPC-2 SEQID 6	A	*K. pneumoniae*	EU784136
CTX-M-15	pBR-CBST-CTX-M-15 SEQ ID 7	A	*K. pneumoniae*	JF775516
SHV-12	pBR-CBST-SHV-12 SEQ ID 8	A	*K. pneumoniae*	AY008838
P99 AmpC	pBR-CBST-P99 AMPC SEQ ID 9	C	*E. cloacea*	XO7274
OXA-15	pBR-CBST-OXA-15 SEQ ID 10	D	*P. aeruginosa*	PAU63835
KPC-4	pBR-CBST-KPC-4 SEQ ID 11	A	*K. pneumoniae*	EU447304
DHA-1	pBR-CBST-DHA-1 SEQ ID 12	C	*K. pneumoniae*	AY585202
ADC-33	pBR-CBST-ADC-33 SEQ ID 13	C	*A.baumannii*	EU687478

Nucleotide Sequences of pBR-CBST Plasmids (Containing β-Lactamase or *cat* Genes) Used in the *E. coli* Isogenic Strains (relevant restriction sites are underlined; β-lactamase sequences in all caps, *tetA* sequence is in italics)

pBR-CBST-cat SEQ ID 5

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Example 100: *Standard BLI Potentiation MIC Assay*

The ability of compounds to potentiate the activity of β-lactams was demonstrated by determining the minimum inhibitory concentrations (MIC) of β-lactam and BLI compound combinations against various β-lactamase producing bacterial strains using the broth microdilution method. The experimental protocol was performed according to Clinical and Laboratory Standards Institute (CLSI) guidelines with modifications as described below (CLSI guidelines can be derived from the CLSI document M07-A9 published in January 2012: "Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria That Grow Aerobically; Approved Standard-Ninth Edition").

To prepare for MIC testing, frozen glycerol stocks of clinical isolates (*Klebsiella pneumoniae, Eschericia coli, Enterobacter spp, Citrobacter spp,* or *Pseudomonas aeruginosa*) were used to streak for isolated colonies on rich, non-selective, tryptic soy agar

containing 5% sheep's blood (TSAB). Frozen glycerol stocks of laboratory engineered, isogenic *E. coli* strains, which contain cloned β-lactamase expressing plasmids were used to streak for isolated colonies on rich, selective LB agar supplemented with 25 μg/mL tetracycline to maintain the plasmid. All strains were incubated at 37°C for 18-24 hrs.

On the day of testing, primary cultures were started by scraping off 5-10 colonies from the TSAB plates containing clinical strains or the tetracycline supplemented LB plates containing engineered strains. The clinical strain material was suspended in ~5 mL of cation adjusted Mueller Hinton Broth (CAMHB) in 14 mL culture tubes. The engineered strain material was suspended in CAMHB (supplemented with 25 μg/mL tetracycline) in 14 mL culture tubes. All strains were incubated at 37°C with aeration (200 rpm) for ~2 hrs until the optical density at 600 nm (OD600) was ≥0.1.

The two compound components of the assay were each diluted in CAMHB and added to the 96-well broth microdilution assay plates. 50 μL of the β-lactam was added to each well of the assay plate in 2-fold dilutions with final concentrations ranging from 128 to 0.13 μg/mL. 25 μL of the BLI compound was added to all wells in the broth microdilution plates at a final concentration of 4 μg/mL. Inoculum cultures were prepared by standardizing the primary cultures to OD600 = 0.1 and then adding 20 μL of the adjusted primary culture per 1 mL CAMHB for clinical strains or CAMHB (supplemented with tetracycline at 100 μg/mL) for engineered strains, so that the final inoculum density was ~10^5 colony forming units per milliliter. Diluted inoculum cultures were used to inoculate 25 μL per well in 96-well broth microdilution assay plates. The final volume of each well was 100 μL and contained a β-lactam at different concentrations, a BLIcompound at 4 μg/mL concentration, the bacterial culture at an OD600 of approximately 0.001 and when necessary tetracycline at 25 μg/mL.

Plates were incubated for 18-20 hours at 37°C with aeration (200 rpm). Following incubation, growth was confirmed visually placing plates over a viewing apparatus (stand with a mirror underneath) and then OD600 was measured using a SpectraMax 340PC384 plate reader (Molecular Devices, Sunnyvale, CA). Growth was defined as turbidity that could be detected with the naked eye or achieving minimum OD600 of 0.1. MIC values were defined as the lowest concentration producing no visible turbidity.

MIC values of representative compounds are shown in Table II.

Example 101: *Synergy MIC (sMIC) Assay*

The synergy MIC (sMIC) assay determines the concentration of the BLI required to potentiate the activity of a fixed concentration of a β-lactam antibiotic against β-lactamase

producing bacterial strains. The experimental protocol was performed according to Clinical and Laboratory Standards Institute (CLSI) guidelines with modifications as described below (CLSI guidelines can be derived from the CLSI document M07-A9 published in January 2012: "Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria That Grow Aerobically; Approved Standard-Ninth Edition"). The assay is set-up by serially diluting the BLI across 11 of the 12 wells in each row of a 96-well broth microdilution assay plate, adding the β-lactam at a fixed concentration to all wells in the assay plate, inoculating the assay plate with bacterial strains, and determining the lowest concentration of BLI required to inhibit overnight bacterial growth. Bacterial growth in the 12th well of the assay plate, which contains the β-lactam at a fixed concentration but does not contain any BLI, demonstrates that the bacterial strains are resistant to the β-lactam antibiotic (e.g ceftolozane) at the fixed concentration of 4 μg/mL.

To prepare for MIC testing, frozen glycerol stocks of clinical isolates (*Klebsiella pneumoniae, Eschericia coli, Enterobacter spp, Citrobacter spp,* or *Pseudomonas aeruginosa*) were used to streak for isolated colonies on rich, non-selective, tryptic soy agar containing 5% sheep's blood (TSAB). Frozen glycerol stocks of laboratory engineered, isogenic *E. coli* strains, which contain cloned β-lactamase expressing plasmids were used to streak for isolated colonies on rich, selective LB agar supplemented with 25 μg/mL tetracycline to maintain the plasmid. All strains were incubated at 37°C for 18-24 hrs.

On the day of testing, primary cultures were started by scraping off 5-10 colonies from the TSAB plates containing clinical strains or the tetracycline supplemented LB plates containing engineered strains. The clinical strain material was suspended in ~5 mL of cation adjusted Mueller Hinton Broth (CAMHB) in 14 mL culture tubes. The engineered strain material was suspended in CAMHB (supplemented with tetracycline at 25 μg/mL) in 14 mL culture tubes. All strains were incubated at 37°C with aeration (200 rpm) for ~2 hrs until the OD600 was ≥0.1.

The two compound components of the assay were each prepared in CAMHB and added to the 96-well broth microdilution assay plates. 50 μL of the BLI was added to each well of the assay plate in 2-fold dilutions with final concentrations ranging from 128 to 0.13 μg/mL. 25 μL of the β-lactam was added to all wells in the broth microdilution plates at a final concentration of 4 μg/mL. Inoculum cultures were prepared by standardizing the primary cultures to OD600 = 0.1 and then adding 20 μL of the adjusted primary culture per 1 mL CAMHB for clinical strains or CAMHB (supplemented with tetracycline at 100 μg/mL)

for isogenic strains, so that the final inoculum density was ~10^5 colony forming units per milliliter. Diluted inoculum cultures were used to inoculate 25 µL per well in 96-well broth microdilution assay plates. The final volume of each well was 100 µL and contained a BLI at different concentrations, a β-lactam at 4 µg/mL concentration, the bacterial culture at an OD600 of approximately 0.001 and when necessary tetracycline at 25 ug/mL.

Interpreting the sMIC data:

Plates were incubated for 18-20 hours at 37°C with aeration (200 rpm). Following incubation, growth was confirmed visually placing plates over a viewing apparatus (stand with a mirror underneath) and then OD600 was measured using a SpectraMax 340PC384 plate reader (Molecular Devices, Sunnyvale, CA). Growth was defined as turbidity that could be detected with the naked eye or achieving minimum OD600 of 0.1. sMIC values were defined as the lowest concentration producing no visible turbidity.

The sMIC values represent the amount of BLI required to potentiate the activity of 4 µg/ml of CXA-101 (Ceftolozane) or ceftazidime to inhibit the growth of the β-lactamase producing bacteria.

sMIC values of representative compounds are shown inTable III.

Example 102: *Inhibition Kinetics*

Inhibition or inactivation of KPC-2 by test inhibitors was assessed using 100 µM nitrocefin (NCF) as a reporter substrate. Assays were performed in 1x PBS pH 7.4, 0.1 mg/ml BSA, in 96-well half area plates, 50 µl reaction volume. NCF was dissolved in DMSO and diluted in assay buffer. Test inhibitors were dissolved in water or DMSO and serially diluted in the assay with final concentrations between 2000 – 0.195 µM.

The enzyme activity in the presence of varying concentrations of test inhibitor was determined by monitoring the hydrolysis of NCF spectrophotometrically at 486 nm, for 5 minutes, 25°C, using a SpectraMax Plus384 microplate reader with SoftMax Pro software (Molecular Devices). Data analysis was performed using GraphPad Prism (GraphPad Software, Inc.).

Progress curves were fit to a first-order rate decay equation (Eq. 1) to determine $k_{observed}$ (k_{obs}).

k_{obs} vs. inhibitor concentration [I] curves were then fit to Eq.2 to determine the inhibitor dissociation constant (K) and the first order rate constant of enzyme inactivation at infinite

inhibitor concentration (k_{inact}). Table IV shows kinetics results from representative test compounds. A larger k_{inact} /K ratio indicates a more effective enzyme inactivator.

Eq. 1

$Y_t=V_0*(1-e^{(-k_{obs}*t)})/k_{obs}$

Where Y is the absorbance at time t, V_0 is the uninhibited enzyme velocity, k_{obs} is the observed rate constant of the enzyme inactivation.

Eq. 2

$k_{obs}=k_{inact}*[I]/([I] + K(1 + S/K_m))$

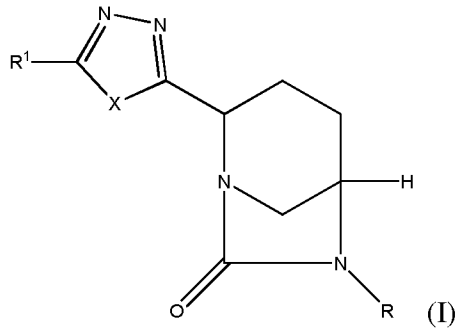
Where S is the NCF concentration, K_m is the KPC-2 K_m for NCF.

Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with the true scope and spirit of the invention being indicated by the following claims.

CLAIMS

We claim:

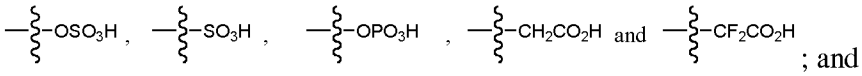
1. A compound of Formula (I) or a pharmaceutically acceptable salt thereof:



(I)

wherein X is selected from O and S;

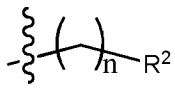
R is selected from



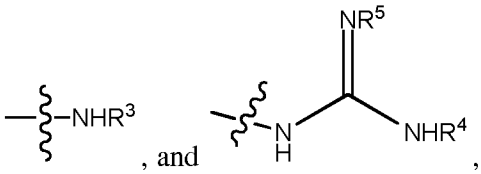
; and

R^1 is selected from:

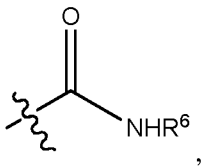
a. hydrogen;

b. ,

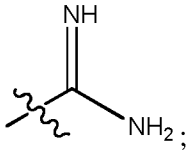
wherein R^2 is selected from



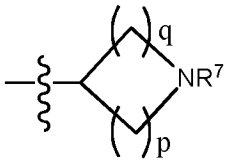
wherein each of R^3, R^4 and R^5 is independently selected from hydrogen, (C_1-C_3)-alkyl, aminoalkyl, aminocycloalkyl, and hydroxyalkyl, and n is selected from 1, 2 and 3;

c. ,

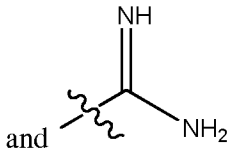
wherein R^6 is H, (C_2-C_3) alkylamino, and



d. amino;

e. ,

wherein R^7 is selected from H, (C_1-C_3)-unsubstituted alkyl, amino-(C_2-C_3)-alkyl, aminocycloalkyl, hydroxyalkyl,

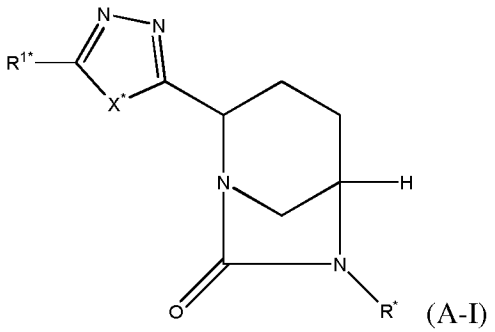


and wherein each of p and q is independently selected from 1 and 2; and

f. $-CH(R^8)CH_2NH_2$

wherein R^8 is selected from amino and hydroxyl.

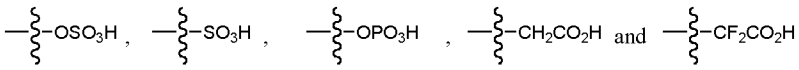
2. A compound of Formula (A-I) or a pharmaceutically acceptable salt thereof:



(A-I)

wherein X^* is selected from O and S;

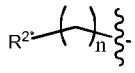
R^* is selected from



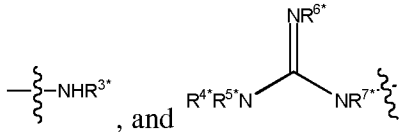
; and

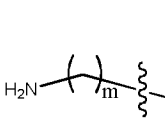
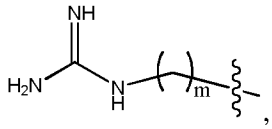
R^{1*} is selected from:

a. hydrogen;

b. ,

wherein R^{2*} is selected from

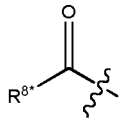
, and ,

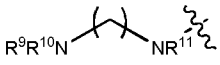
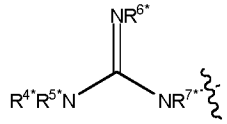
R^{3*} is selected from hydrogen, $(C_1$-$C_3)$-alkyl, aminoalkyl, aminocycloalkyl, hydroxyalkyl,  and ,

each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is independently selected from hydrogen or $(C_1$-$C_6)$-alkyl, aminoalkyl, aminocycloalkyl, and hydroxyalkyl, provided that at least one of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is hydrogen,

n is selected from 1, 2, 3 and 4, and

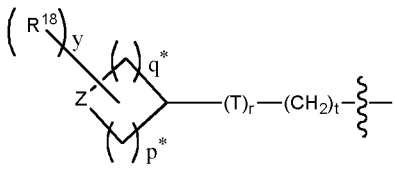
m is selected from 1, 2 and 3;

c. ,

wherein R^{8*} is selected from NH_2,  or 

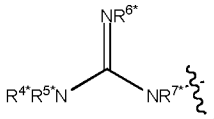
wherein each of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is as described previously and each of R^9, R^{10}, and R^{11} is independently selected from hydrogen or $(C_1$-$C_6)$-alkyl, provided that at least one of R^9, R^{10}, and R^{11} is hydrogen;

d. amino;

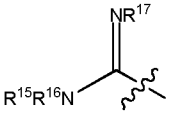
e. ,

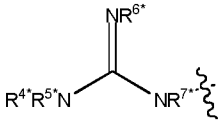
wherein Z is selected from $CR^{12}R^{13}$ or NR^{14},

each of R^{12} and R^{13} is independently selected from H, NH_2 and


, wherein each of R^{4*}, R^{5*}, R^{6*} and R^{7*} is as described previously,

alternatively, R^{12} and R^{13} together with the carbon to which they are attached, form a cycloalkyl or heterocyclyl ring containing 4-6 ring members,

R^{14} is selected from H and , wherein each of R^{15}, R^{16} and R^{17} is independently selected from hydrogen, $(C_1\text{-}C_6)$-alkyl, aminoalkyl, aminocycloalkyl, and hydroxyalkyl, provided that at least one of R^{15}, R^{16} and R^{17} is hydrogen,

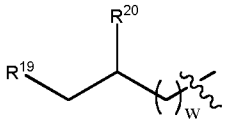
R^{18} is selected from NH_2 and , wherein each of R^{4*}, R^{5*}, R^{6*} and R^{7*} is as described previously,

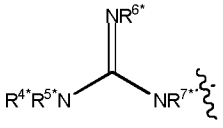
each of p* and q* is independently selected from 0, 1, 2 and 3,

T is selected from NH and O

t is selected from 0, 1, 2, 3, and 4, and

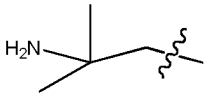
each of r and y is independently selected from 0 and 1;

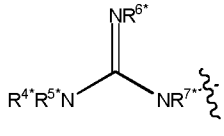
f. ,

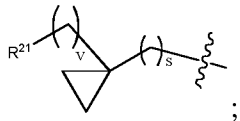
wherein R^{19} is selected from NH_2 and , wherein each of R^{4*}, R^{5*}, R^{6*} and R^{7*} is as described previously,

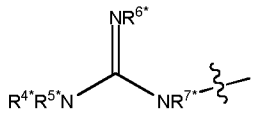
R^{20} is selected from amino and hydroxyl, and

w is selected from 0 and 1;

g. ;

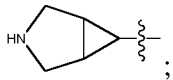
h. , wherein each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is as described previously;

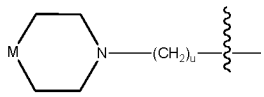
i. ;

wherein R^{21} is selected from NH_2, -NH(C_1-C_3)-alkyl and , wherein each of R^{4*}, R^{5*}, $R^{6*}$and R^{7*} is as described previously,

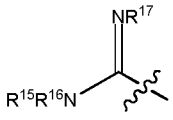
s is selected from 0 and 1, and

v is selected from 0, 1, 2, and 3;

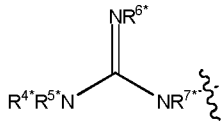
j. ;

k. ,

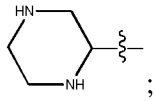
wherein M is selected from NR^{22}, $CR^{23}R^{24}$ and O,

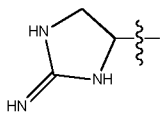
wherein R^{22} is H, , wherein each of R^{15}, R^{16} and R^{17} is as described previously,

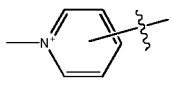
each of R^{23} and R^{24} is independently selected from H, NH_2 and

 wherein each of R^{4*}, R^{5*}, $R^{6*}$and $R^{7*}$is as described previously, and

u is selected from 0, 1 and 2;

l. ;

m. ; and

n. .

3. A pharmaceutical composition comprising a compound of claim 2 and at least 1 β-lactam antibiotic.
4. The pharmaceutical composition of claim 3 wherein the β-lactam antibiotic is a cephalosporin.
5. The pharmaceutical composition of claim 4 wherein the cephalosporin is Ceftolozane.
6. The pharmaceutical composition of claim 3 wherein the β-lactam antibiotic is a carbapenem.
7. The pharmaceutical composition of claim 3 wherein the β-lactam antibiotic is a monobactam.
8. A method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition according to claim 3.
9. A method of treating a bacterial infection comprising administering to a subject in need thereof, a therapeutically-effective amount of a β-lactam antibiotic in conjunction with a compound of claim 2.
10. The method of claim 9 wherein the β-lactam antibiotic is a cephalosporin.
11. The method of claim 10 wherein the cephalosporin is Ceftolozane.
12. The method of claim 9 wherein the β-lactam antibiotic is a carbapenem.
13. The method of claim 9 wherein the β-lactam antibiotic is a monobactam.
14. The method of either of claims 8 or 9 wherein the bacterial infection is caused by bacteria that produce a class A, class C or class D β-lactamase.
15. The method of claim 14 wherein the bacterial infection is caused by bacteria that produce a class A or class C β-lactamase.
16. The method of claim 14 wherein the bacterial infections is caused by bacteria selected from *Acinetobacter* spp., *Acinetobacter baumannii*, *Citrobacter* spp., *Escherichia* spp., *Escherichia coli*, *Haemophilus influenzae*, *Morganella morganii*, *Pseudomonas aeruginosa*, *Klebsiella* spp., *Klebsiella pneumoniae*, *Enterobacter* spp., *Enterobacter cloacae and Enterobacter aerogenes Pasteurella* spp, *Proteus* spp., *Proteus mirabilis*, *Serratia* spp, *Serratia marcescens*, and *Providencia* spp.
17. The method of claim 14 wherein the bacterial infection is caused by bacteria that produce a KPC-2 or KPC-3 β-lactamase.
18. The method of claim 14 wherein the bacterial infection is caused by bacteria that produce an OXA-15 β-lactamase.

19. The method of either of claims 8 or 9 wherein the bacterial infection is caused by β-lactam resistant bacteria.

20. A method of treating or a bacterial infection in a subject in need thereof, comprising the steps of

    a. administering to the subject a compound of claim 2; and

    b. administering to the subject a therapeutically-effective amount of a β-lactam antibiotic.

21. A method of treating a bacterial infection in a subject in need thereof, comprising the steps of

    a. administering to the subject a therapeutically-effective amount of a β-lactam antibiotic; and

    b. administering to the subject a compound of claim 2.

22. Use of a compound of claim 2 for the manufacture of a medicament for the treatment of a bacterial infection in a subject.

23. Use of a composition of claim 3 for the manufacture of a medicament for the treatment of a bacterial infection in a subject.

24. The use according to either of claims 22 or 23 wherein the bacterial infection is caused by bacteria that produce a class A, class C or class D β-lactamase.

25. The use according to either of claims 22 or 23 wherein the bacterial infection is caused by bacteria that produce a class A or class C β-lactamase.

26. The use according to either of claims 22 or 23 wherein the bacterial infections is caused by bacteria selected from from *Acinetobacter* spp., *Acinetobacter baumannii*, *Citrobacter* spp., *Escherichia* spp., *Escherichia coli*, *Haemophilus influenzae*, *Morganella morganii*, *Pseudomonas aeruginosa*, *Klebsiella* spp., *Klebsiella pneumoniae*, *Enterobacter* spp., *Enterobacter cloacae and Enterobacter aerogenes Pasteurella* spp, *Proteus* spp., *Proteus mirabilis*, *Serratia* spp, *Serratia marcescens*, and *Providencia* spp

27. The use according to either of claims 22 or 23 wherein the bacterial infection is caused by bacteria that produce a KPC-2 or KPC-3 β-lactamase.

28. The use according to either of claims 22 or 23 wherein the bacterial infection is caused by bacteria that produce an OXA-15 β-lactamase.

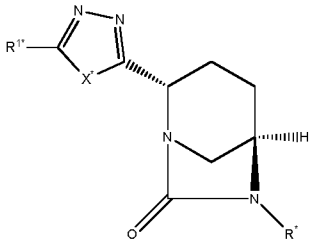
29. The use according to either of claims 22or 23 wherein the bacterial infection is caused by β-lactam resistant bacteria.

30. Use of a compound of claim 2 to inhibit β-lactamase

31. A method of inhibiting β-lactamase comprising administering to a subject a compound of claim 2.

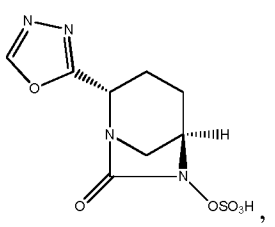
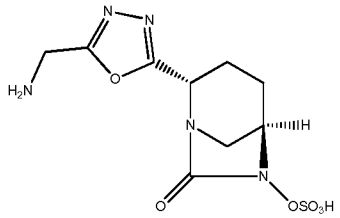
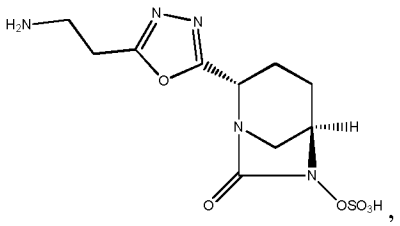
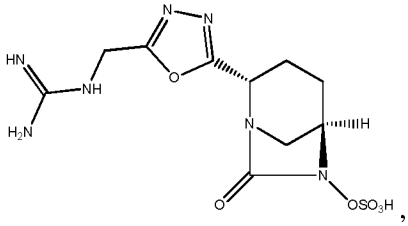
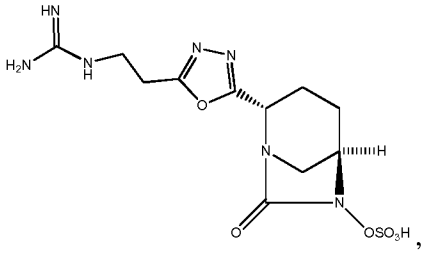
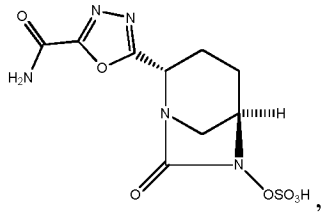
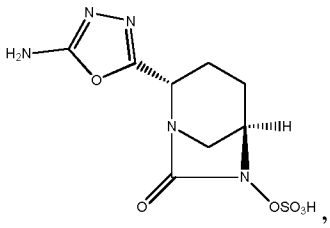
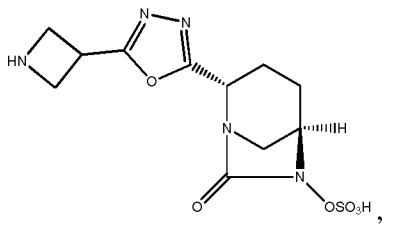
32. A compound of claim 2 wherein the binding affinity of the compound is at least 250 $mM^{-1}s^{-1}$.

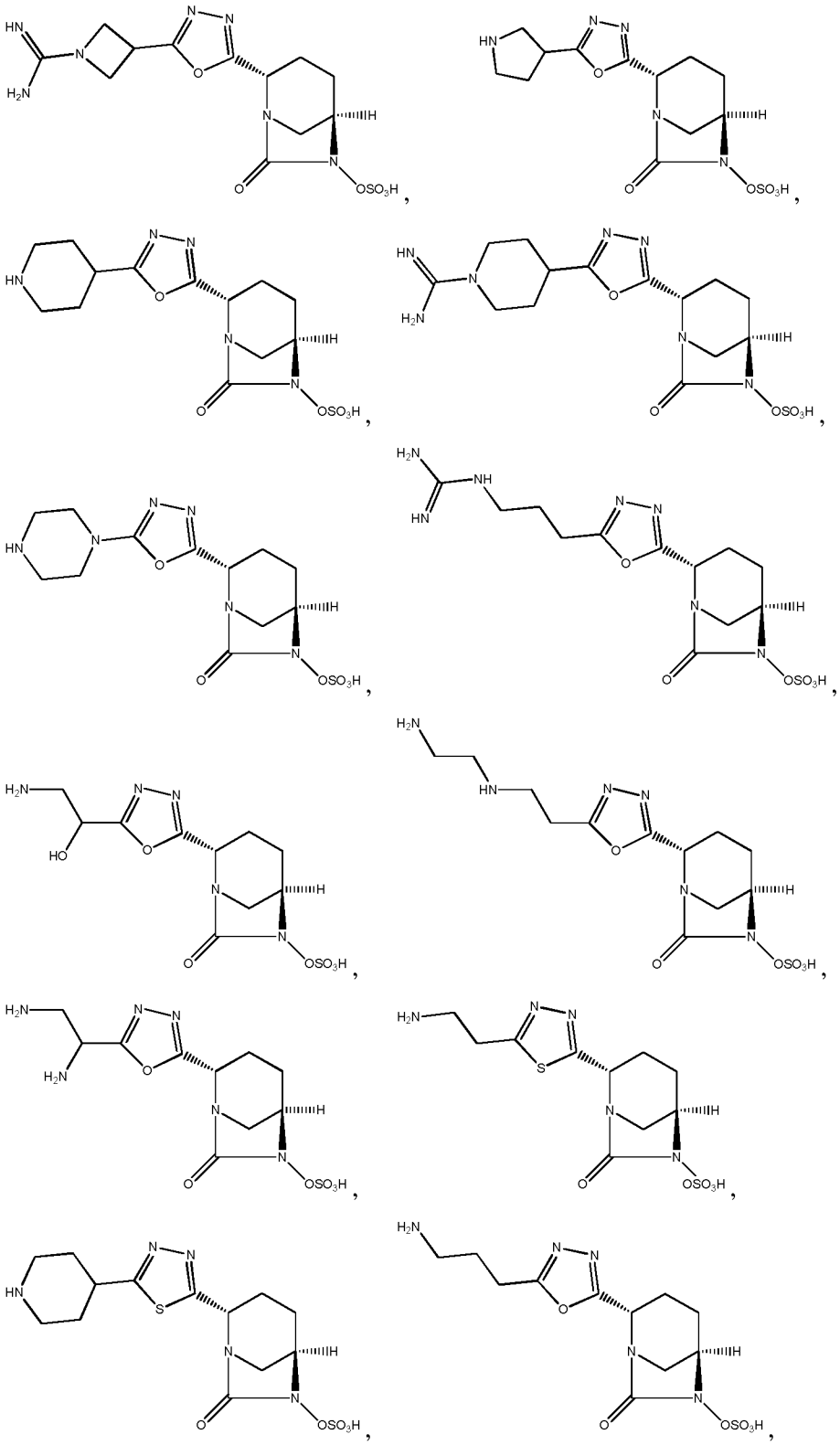
33. The compound of claim 2, wherein the compound of Formula A-I has the stereochemistry specified in Formula A-II

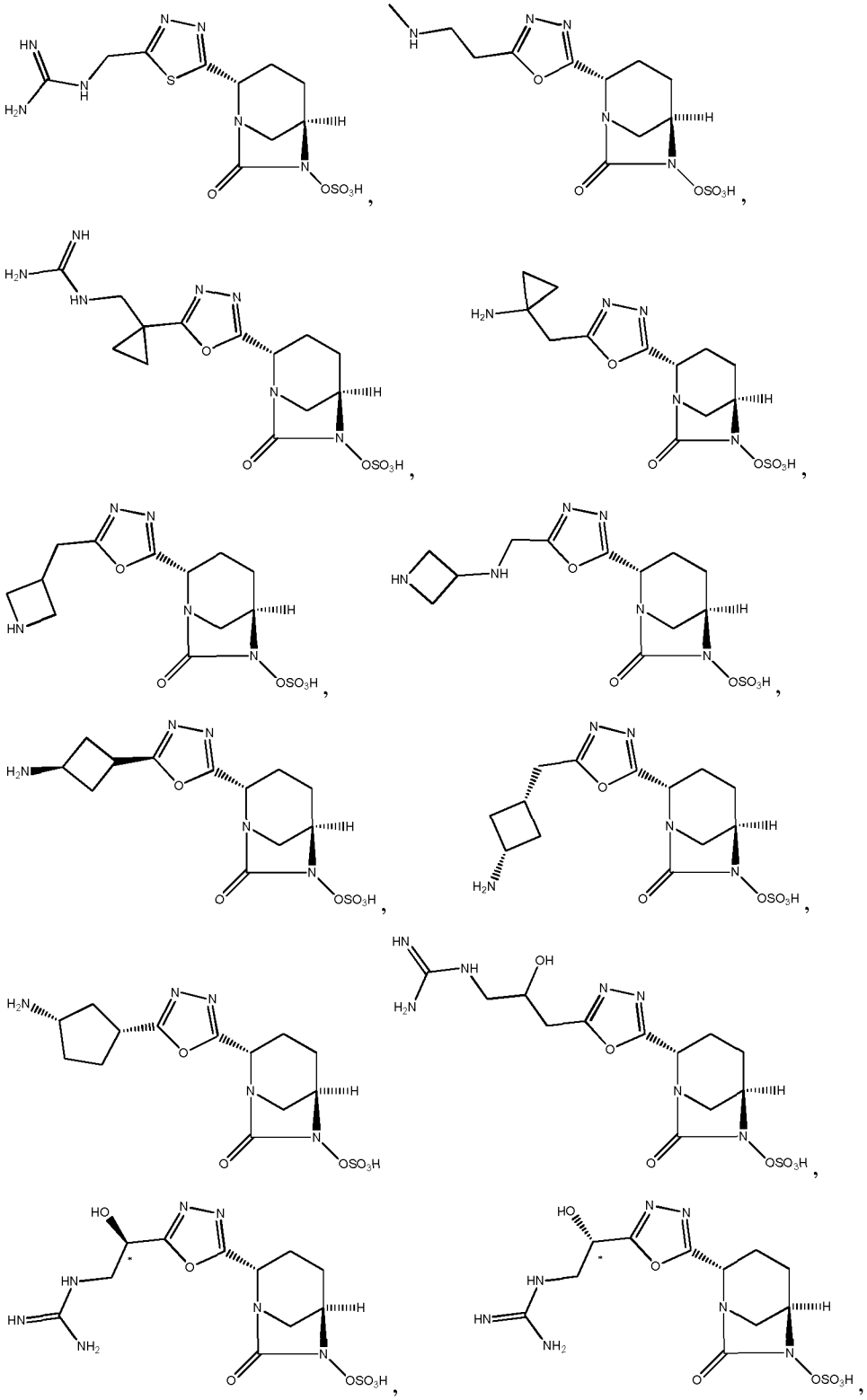

(A-II)

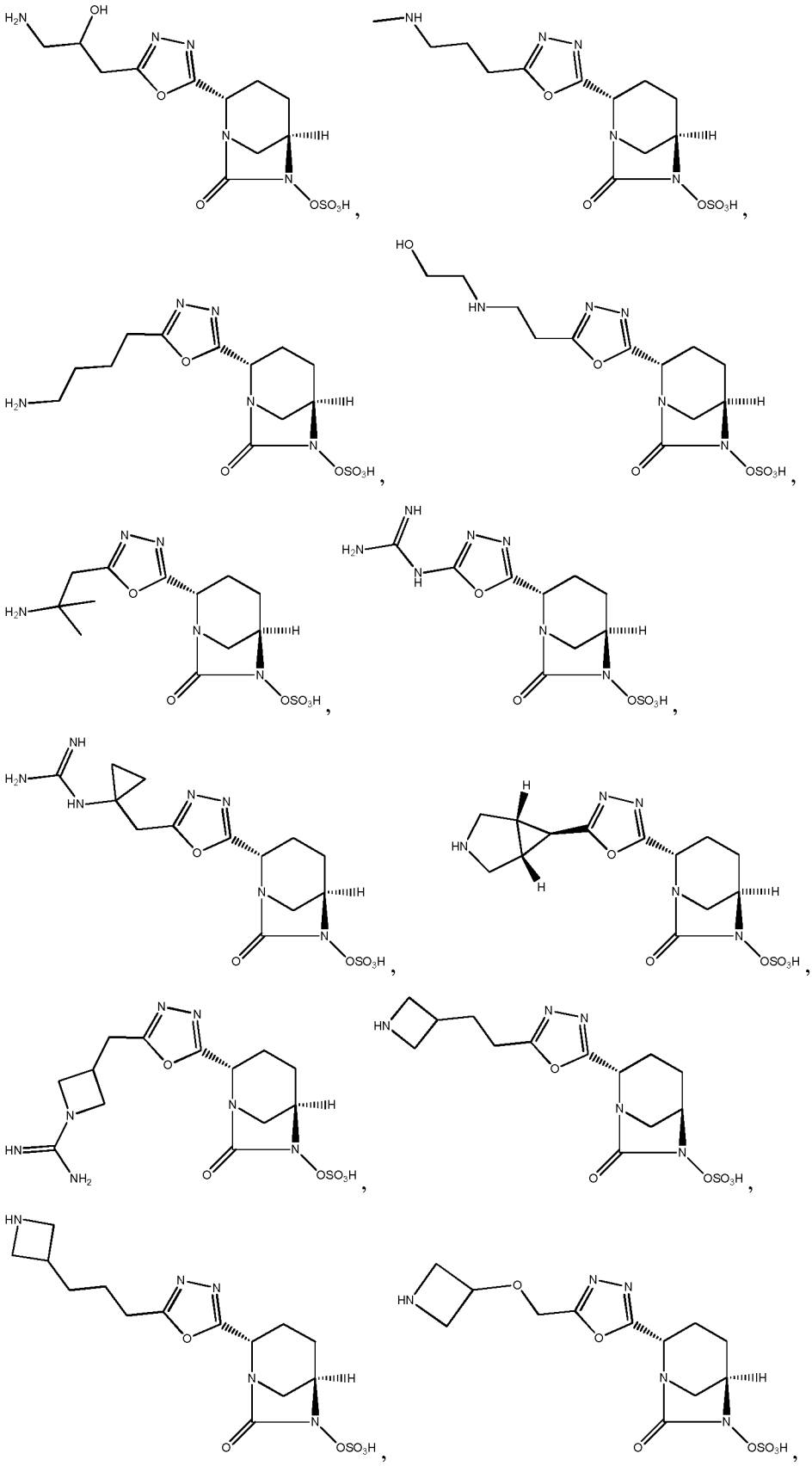
or a pharmaceutically acceptable salt thereof.

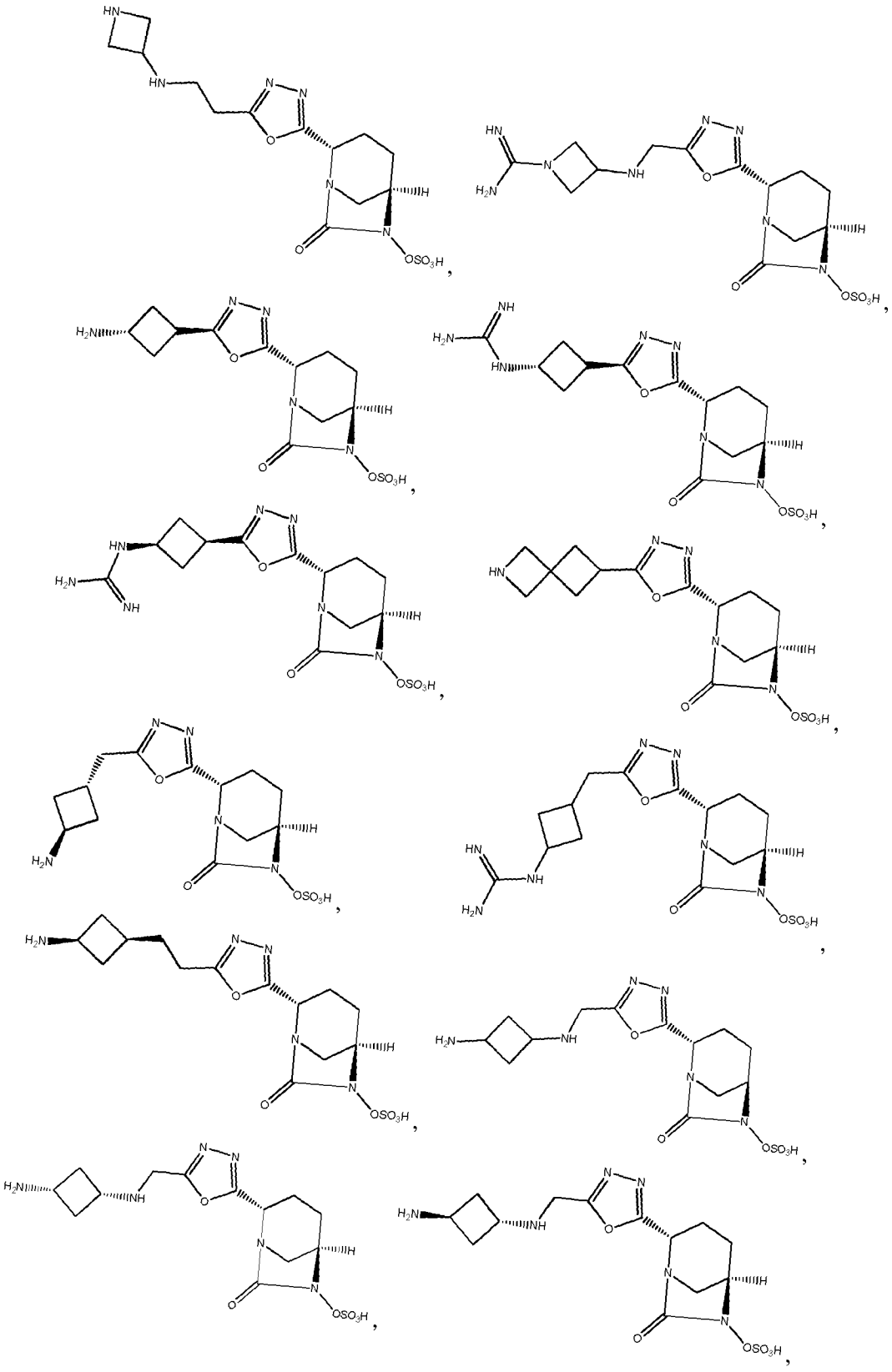
34. The compound of claim 33, or a pharmaceutically acceptable salt thereof selected from

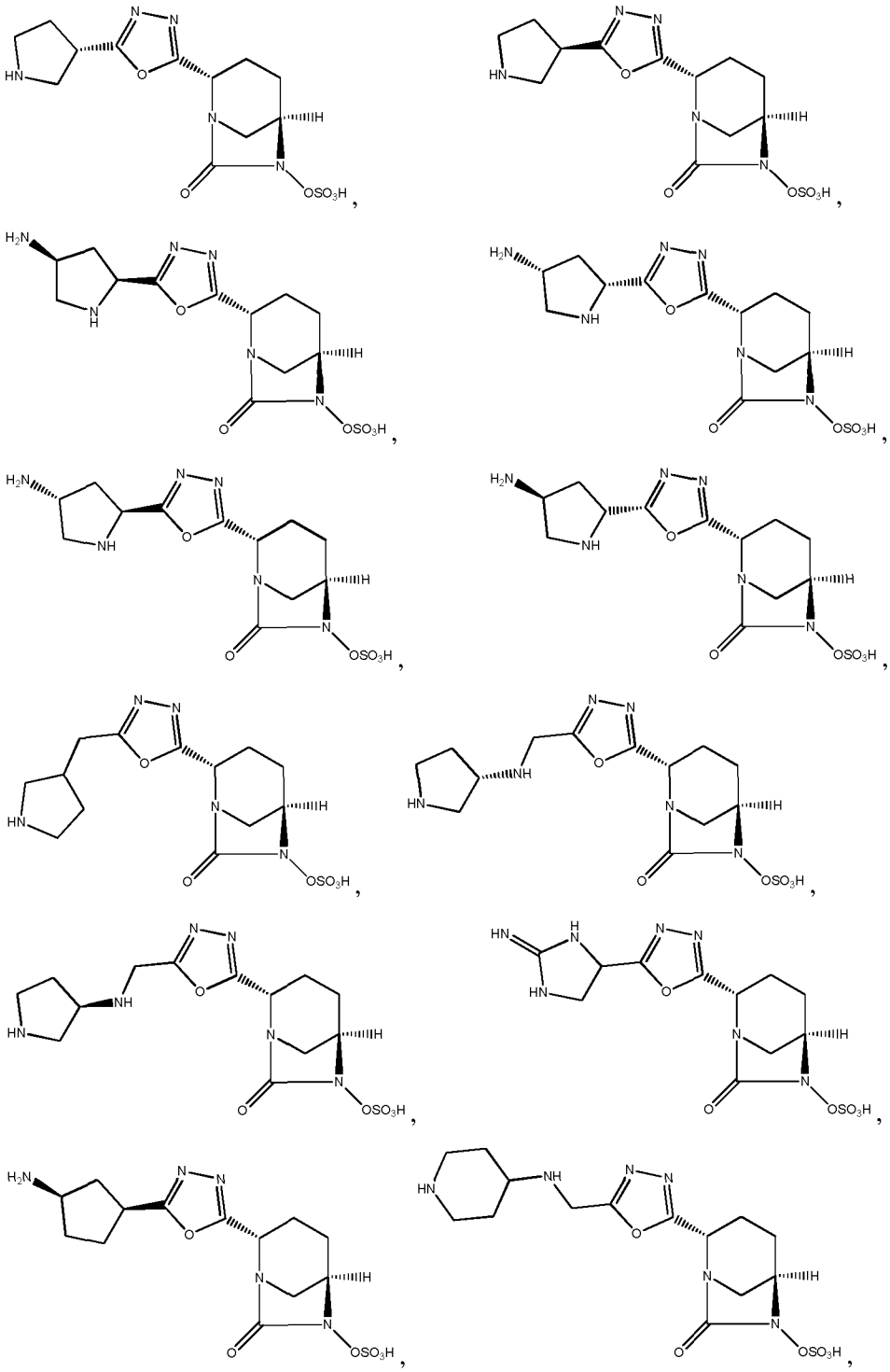

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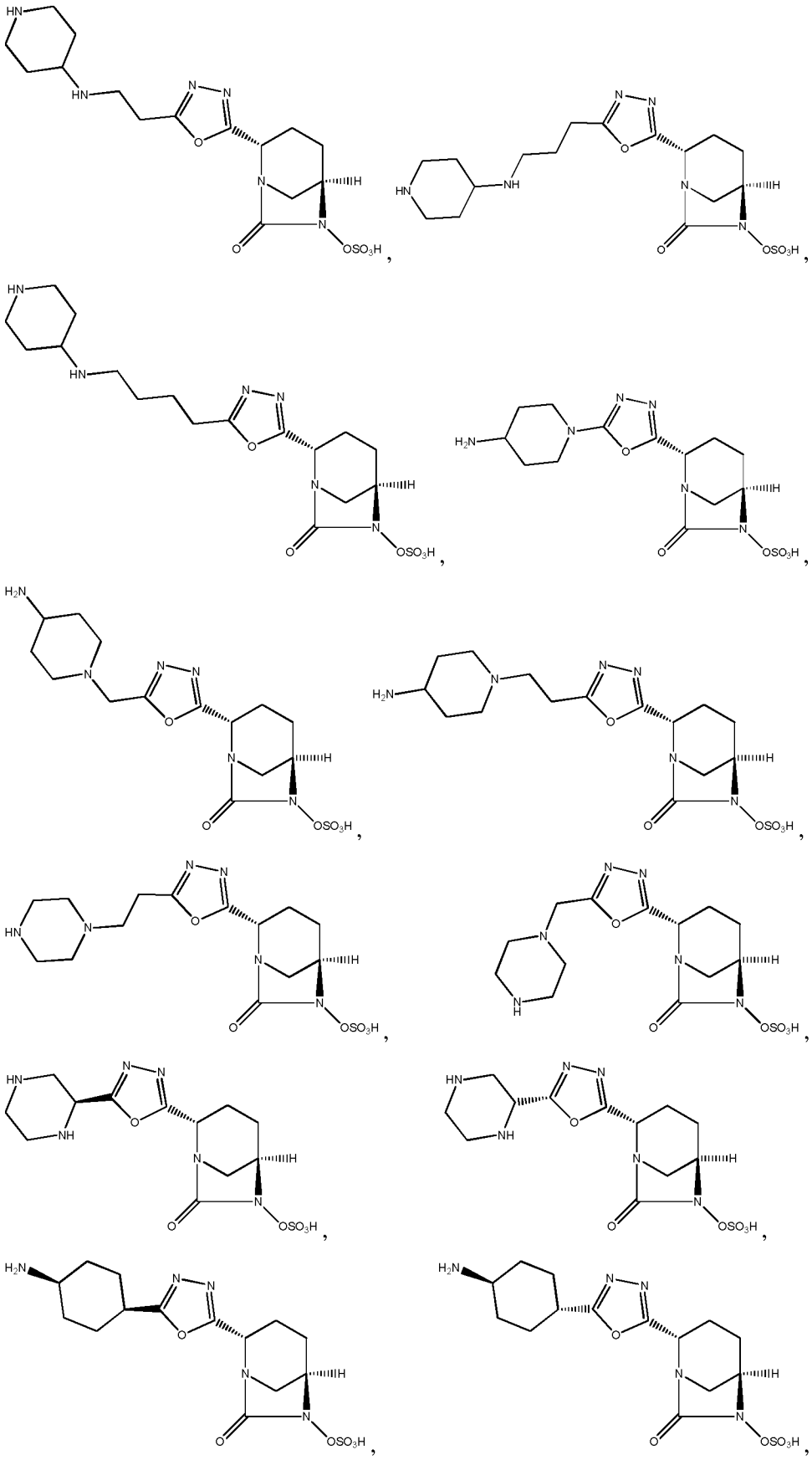


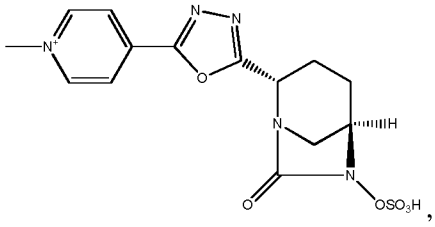


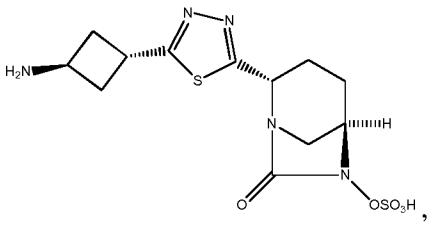


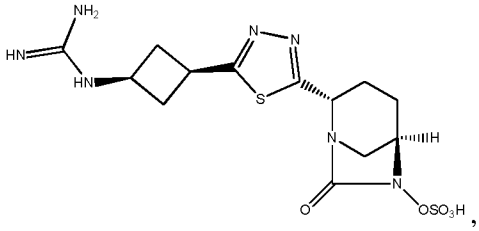


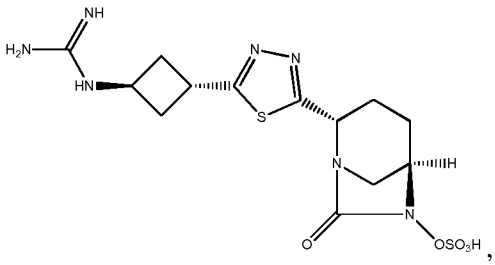


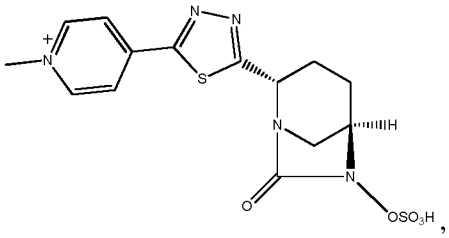


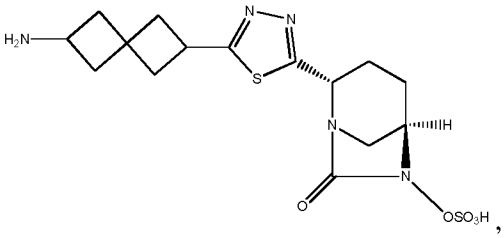


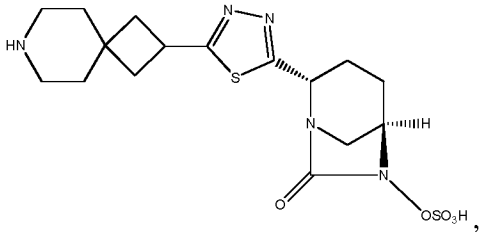


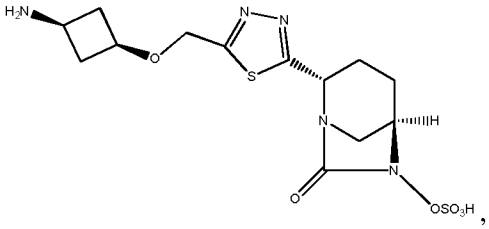


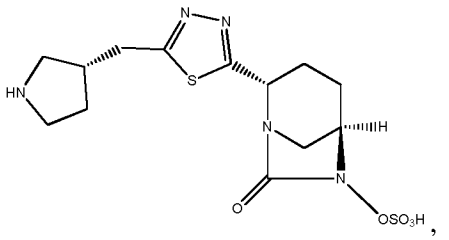


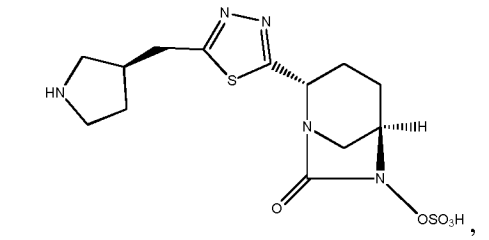


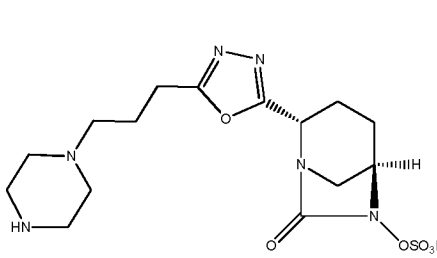


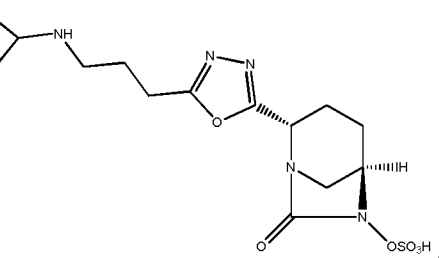




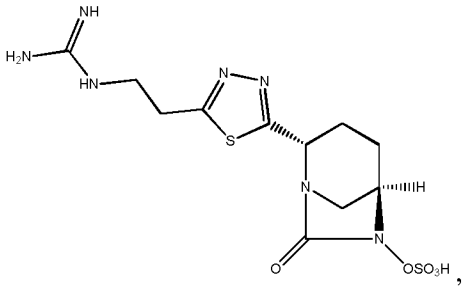
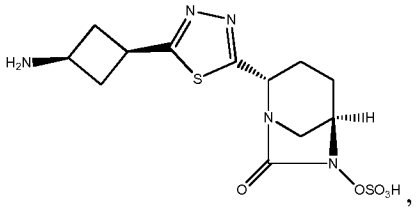
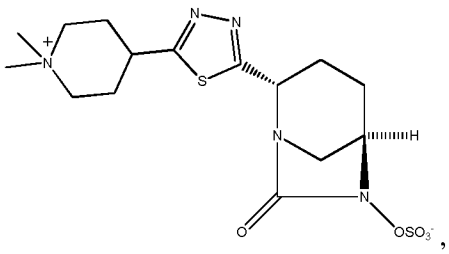
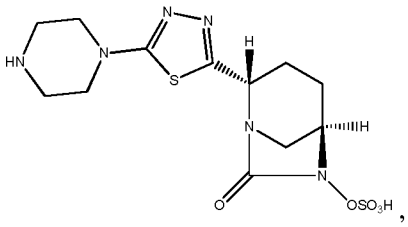
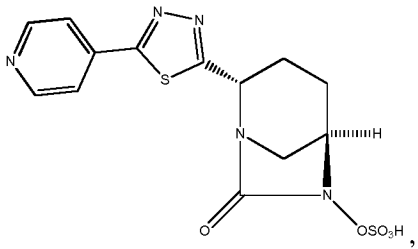
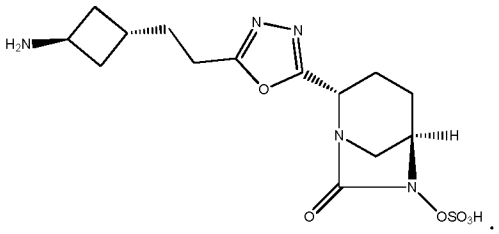




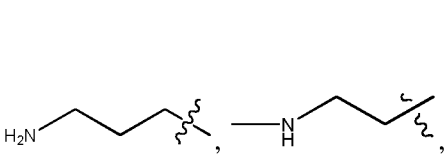


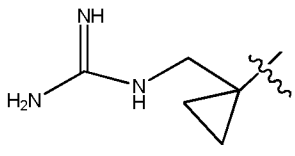
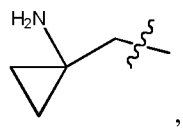
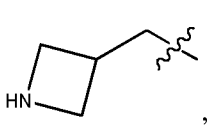
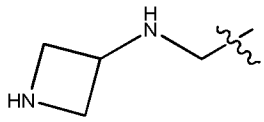
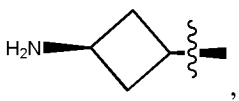
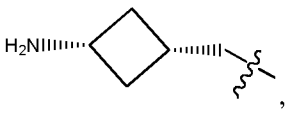
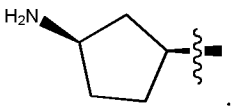


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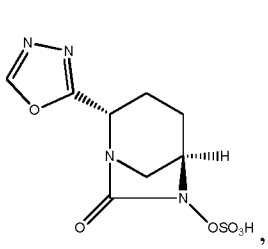
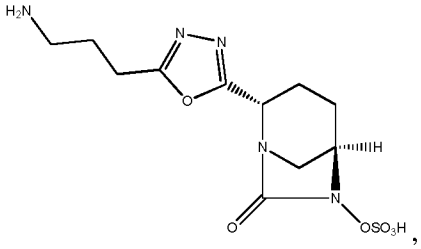
35. The compound according to either of claims 2 or 3 wherein R^{1*} is selected from H,

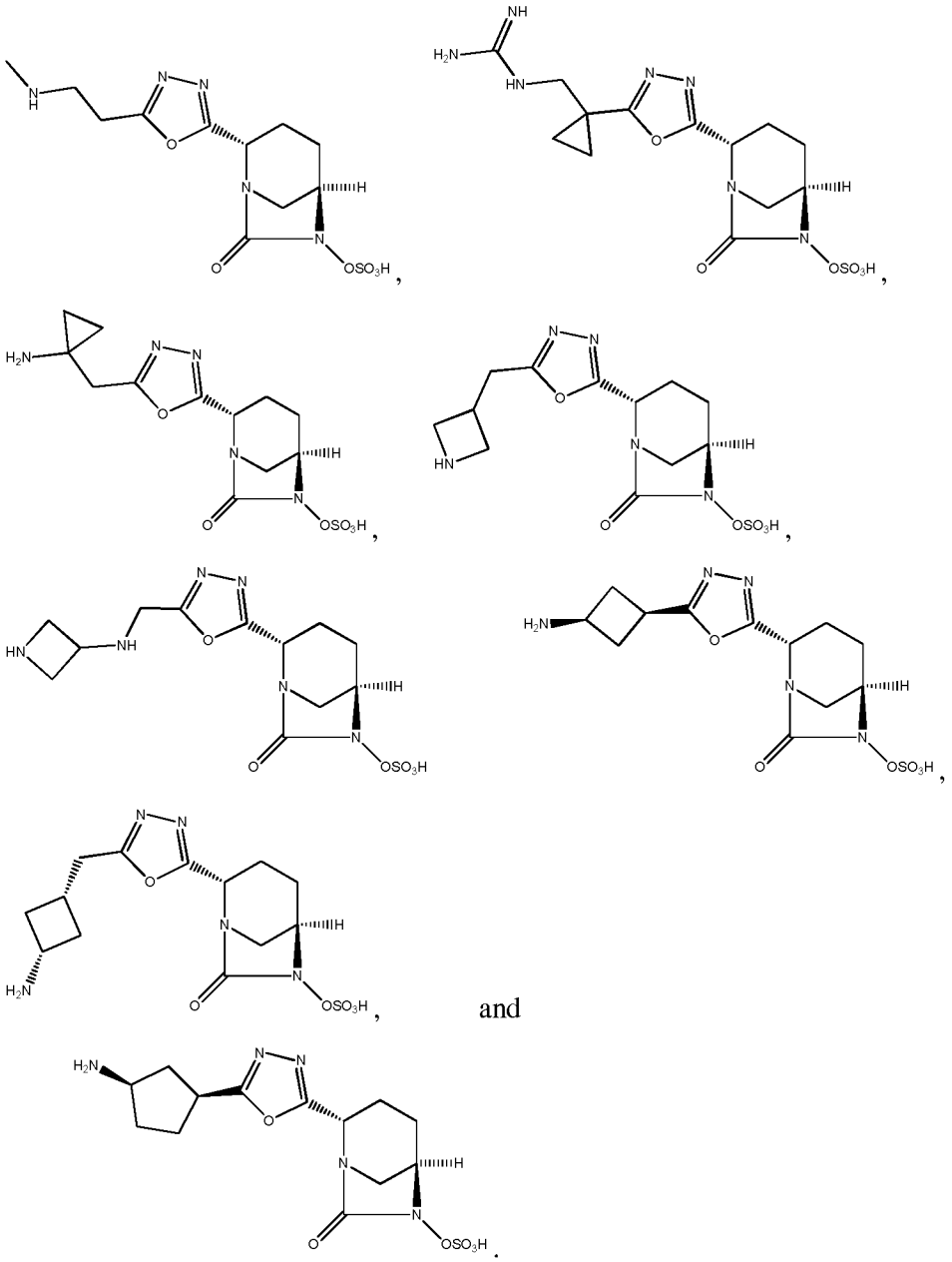

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36. The compound according to claim 35 wherein X is O.

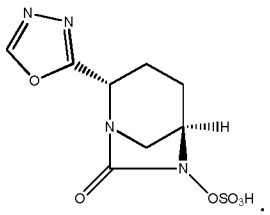
37. The compound according to claim 34 selected from


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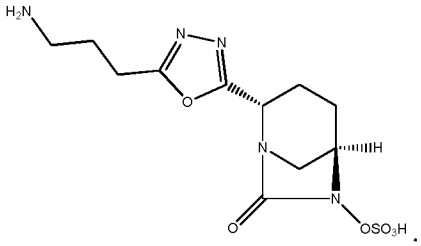


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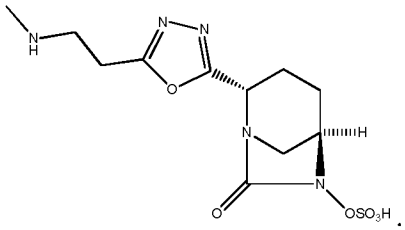
38. The compound according to claim 2 or a pharmaceutically-acceptable salt thereof of the Formula



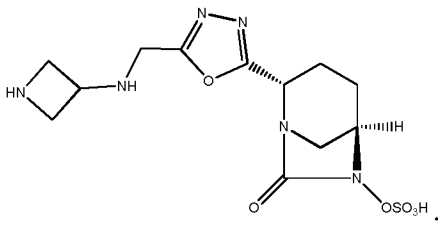
39. The compound according to claim 2 or a pharmaceutically-acceptable salt thereof of the Formula



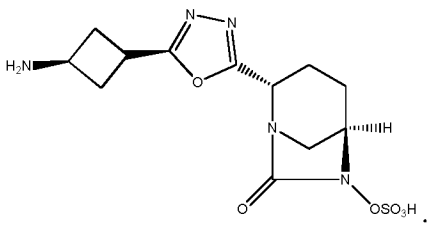
40. The compound according to claim 2 or a pharmaceutically-acceptable salt thereof of the Formula



41. The compound according to claim 2 or a pharmaceutically-acceptable salt thereof of the Formula

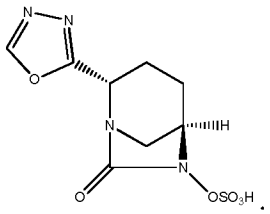


42. The compound according to claim 2 or a pharmaceutically-acceptable salt thereof of the Formula

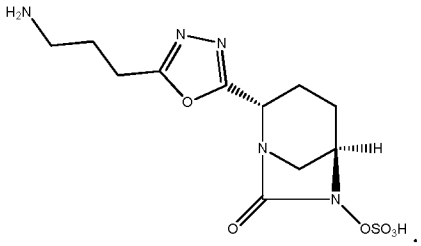


43. A pharmaceutical composition comprising a compound of claim 37 and Ceftolozane.

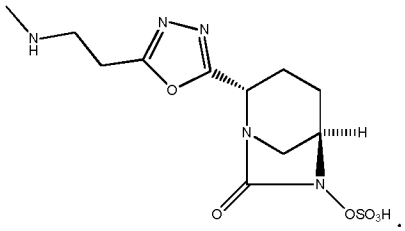
44. The pharmaceutical composition of claim 43 wherein the compound is



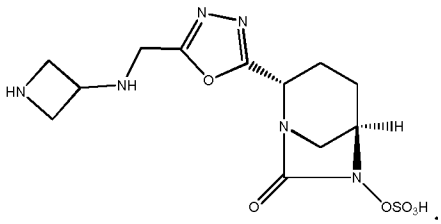
45. The pharmaceutical composition of claim 43 wherein the compound is



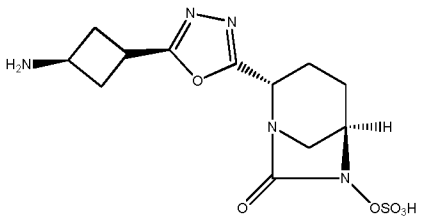
46. The pharmaceutical composition of claim 43 wherein the compound is



47. The pharmaceutical composition of claim 43 wherein the compound is



48. The pharmaceutical composition of claim 43 wherein the compound is



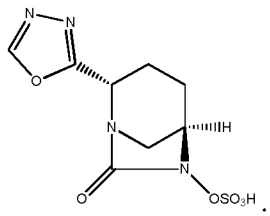
49. A method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition according to claim 44.

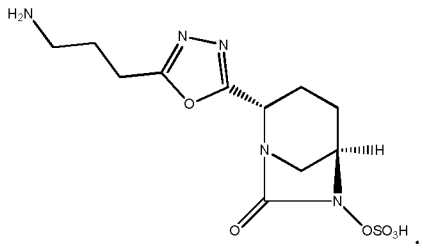
50. A method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition according to claim 45.

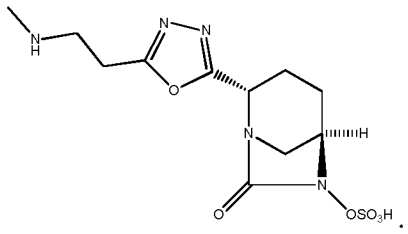
51. A method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition according to claim 46.

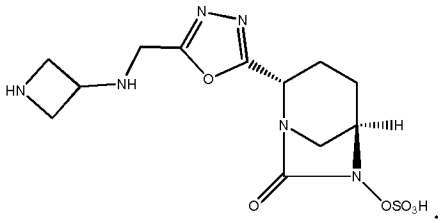
52. A method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition according to claim 47.

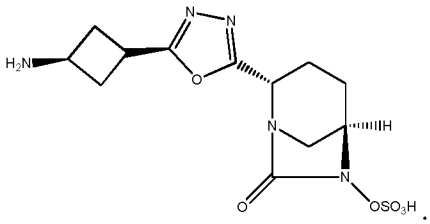
53. A method of treating or preventing a bacterial infection comprising administering to a subject in need thereof a therapeutically-effective amount of the pharmaceutical composition according to claim 48.

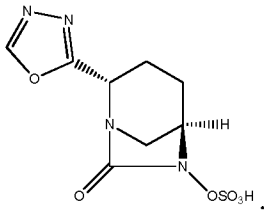
54. The method according to claim 9 wherein β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

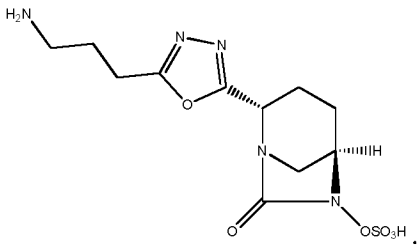
55. The method according to claim 9 wherein β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

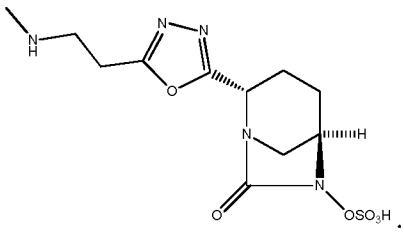
56. The method according to claim 9 wherein β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

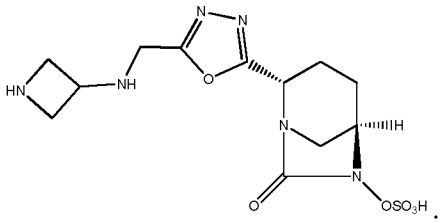
57. The method according to claim 9 wherein β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

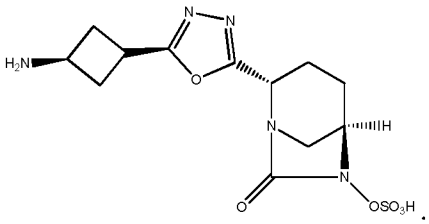
58. The method according to claim 9 wherein β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

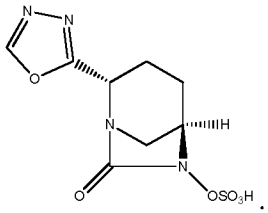
59. The method according to claim 20 wherein β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

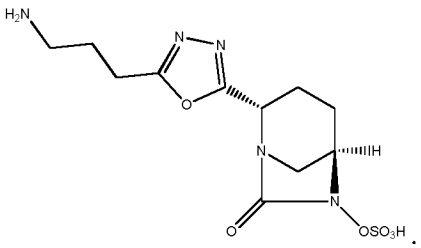
60. The method according to claim 20 wherein β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

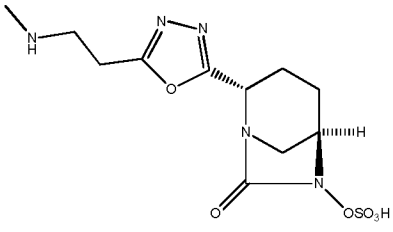
61. The method according to claim 20 wherein β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

62. The method according to claim 20 wherein β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

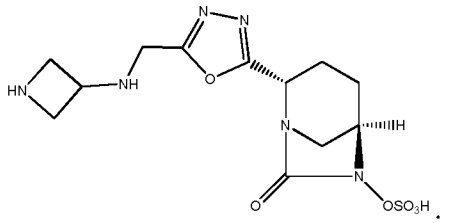
63. The method according to claim 20 wherein the β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

64. The method according to claim 21 wherein the β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

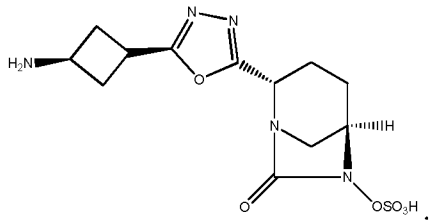
65. The method according to claim 21 wherein the β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

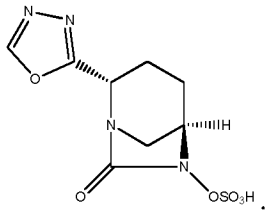
66. The method according to claim 21 wherein the β-lactam antibiotic is Ceftolozane and the compound of claim 2 is .

67. The method according to claim 21 wherein the β-lactam antibiotic is Ceftolozane

and the compound of claim 2 is .

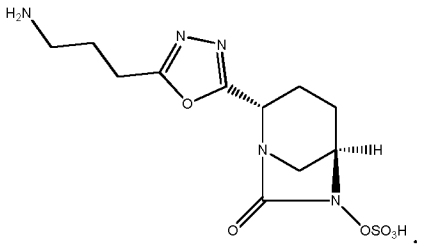
68. The method according to claim 21 wherein the β-lactam antibiotic is Ceftolozane

and the compound of claim 2 is .

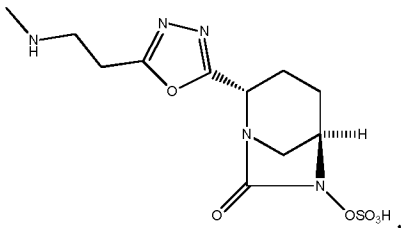


69. The use according to claim 22, wherein the compound is .

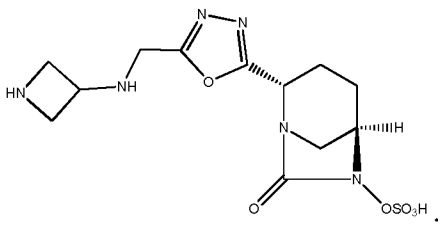
70. The use according to claim 22, wherein the compound is

.

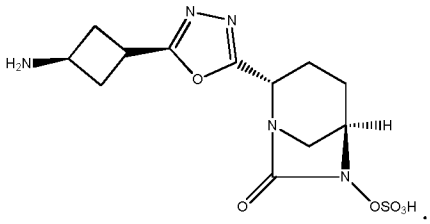
71. The use according to claim 22, wherein the compound is

.

72. The use according to claim 22, wherein the compound is

.

73. The use according to claim 22, wherein the compound is



74. Use of a composition of claims 44 for the manufacture of a medicament for the treatment of a bacterial infection in a subject.

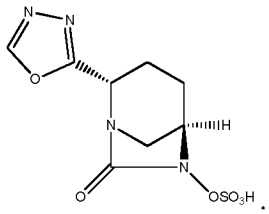
75. Use of a composition of claims 45 for the manufacture of a medicament for the treatment of a bacterial infection in a subject.

76. Use of a composition of claims 46 for the manufacture of a medicament for the treatment of a bacterial infection in a subject.

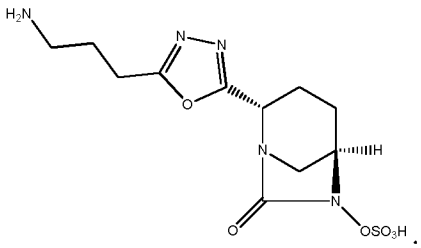
77. Use of a composition of claims 47 for the manufacture of a medicament for the treatment of a bacterial infection in a subject.

78. Use of a composition of claims 48 for the manufacture of a medicament for the treatment of a bacterial infection in a subject.

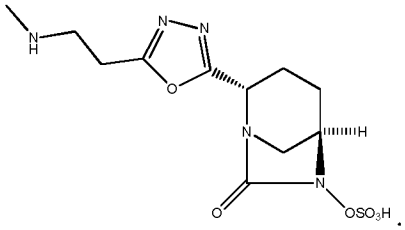
79. The use according to claim 30, wherein the compound is



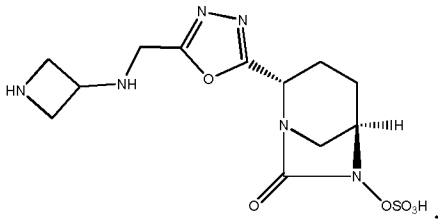
80. The use according to claim 30, wherein the compound is



81. The use according to claim 30, wherein the compound is



82. The use according to claim 30, wherein the compound is



83. The use according to claim 30, wherein the compound is

