

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
3 July 2008 (03.07.2008)

PCT

(10) International Publication Number
WO 2008/079314 A2

(51) International Patent Classification:
A61K 38/17 (2006.01)

(21) International Application Number:

PCT/US2007/026116

(22) International Filing Date:

20 December 2007 (20.12.2007)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

60/876,377 21 December 2006 (21.12.2006) US

(71) Applicant (for all designated States except US): **THE UNITED STATES OF AMERICA**, as represented by **THE SECRETARY OF THE ARMY**, on behalf of **WALTER REED ARMY INSTITUTE OF RESEARCH** [US/US]; 504 Scott Street, Fort Detrick, MD 21702-5012 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **HICKS, Rickey, P.** [US/US]; 1128 Bryson Drive, Greenville, NC 27834-0041 (US). **VENUGOPAL, Divakaramenon** [US/US]; 899 Clopper Road, #t2, Gaithersburg, MD 20878 (US). **BHONSLE, Jayendra** [IN/US]; 13592 Waterford Hills Boulevard, Germantown, MD 20874 (US).

(74) Agents: **ARWINE, Elizabeth.** et al.; U.S.Army Medical Research And Material Command, Attn:MCMr-ZA-J, 504 Scott Street, Fort Detrick, MD 21702-5012 (US).

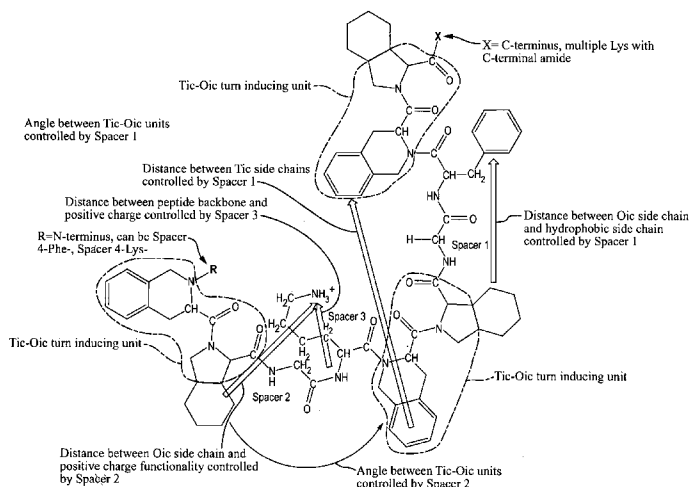
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report

(54) Title: NOVEL ANTI-MICROBIAL PEPTIDOMIMETIC COMPOUNDS AND METHODS TO CALCULATE ANTI-MICROBIAL ACTIVITY



(57) Abstract: This invention encompasses synthetic antimicrobial peptide analogs having certain un-natural amino acids, including the un-natural amino acids hydrophobic tetrahydroisquinolinecarboxylic acid (Tic) and octahydroindolecarboxylic acid (Oic), incorporated into the polypeptide backbone. These antimicrobial peptides (AMPs) are useful to treat infection in humans and other mammals of such bacteria as Gram positive bacteria, Gram negative bacteria and Mycobacterium. Many of the AMPs also exhibit the property of reduced hemolytic activity. The invention also entails 3D-QSAR models and mathematical equations that calculate the biological activity of any peptide sequence against Staphylococcus aureus or Mycobacterium ranae.

WO 2008/079314 A2

NOVEL ANTI-MICROBIAL PEPTIDOMIMETIC COMPOUNDS AND METHODS TO CALCULATE ANTI-MICROBIAL ACTIVITY

This application claims priority from U.S. provisional application 60/876,377, filed December 21, 2006, the entire contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

The focus of this application is novel membrane disruptive antimicrobial peptides (AMPs) with increased selectivity and potency against specific bacterial strains. As described below, this invention encompasses synthetic antimicrobial peptide analogs having certain formulas, including the un-natural hydrophobic amino acids tetrahydroisoquinolinecarboxylic acid (Tic) and octahydroindolecarboxylic acid (Oic). These antimicrobial peptides (AMPs) are useful to treat infection in humans and other mammals caused by such bacteria as Gram positive bacteria, Gram negative bacteria and Mycobacteria. Many of the AMPs also exhibit the property of reduced hemolytic activity.

BACKGROUND OF THE INVENTION

Antimicrobial peptides (AMP) have evolved in almost every class of living organism as a defense mechanism against invading micro-organisms including bacteria, fungi, protozoa and parasites.^{1, 2} As of 2004,³ over 800 antimicrobial peptides had been isolated and characterized from various organisms including humans,⁴ amphibians,⁵ insects, mammals, birds, fish and plants.² AMPs are generally small (10-50 amino acid residues) highly positively charged (+3 to +9)⁶ amphipathic molecules with well defined hydrophobic and hydrophilic regions.^{3, 7}

The exact mechanism of membrane-induced cytotoxicity of these peptides is currently a topic of debate in the literature.⁸ AMPs are broadly divided into two major classes 1) membrane disruptive and 2) non-membrane disruptive.[Powers, 2003 #3]⁸ All membrane-disruptors follow specific steps in the process of interacting with their target

cells.⁹ The first step is the attraction (or movement of the AMP through bulk solution to an area near the surface) of the AMP to the surface of the membrane.¹⁰ The driving force for this attraction is the electrostatic interaction between the positively charged basic amino acids on the AMP and the negatively charged acidic phospholipids found in the targets cell's membrane.^{11, 12 13} The second step is binding of the AMP to the surface of the membrane.^{10,14} In this step the AMP attaches to the surface of the membrane by locating the positively charged side chains relatively close to the negatively charged polar head groups of the phospholipids followed by insertion of the hydrophobic side chains of the AMP into the hydrophobic core of the membrane. During this process conformational changes occur on the AMP that stabilizes the attractive electrostatic and hydrophobic interactions while concurrently minimizing the repulsive interactions between the AMP and the membrane. At lower concentrations the long axis of the AMP is oriented parallel to the surface of the membrane, and is called the S-state.¹⁵ As the concentration of the AMPs increases on the surface of the membrane a critical concentration is reached where aggregation occurs forming complexes of 4-6 AMPs. This induces a change in the orientation of the long axis of the AMPs from parallel to perpendicular relative to the membrane surface resulting in the insertion of the aggregate AMPs into the membrane forming a transmembrane pore, and this is called the I-state.^{14,10}

The membrane-disruptors can be further divided into two sub-classifications; 1) cell selective (i.e. magainins and cecropins) , 2) non-selective (i.e. melittin and pardaxin).¹⁶ As the name implies, cell selective AMPs exhibit potent activity against bacterial cells while being inactive against mammalian cells. Non-selective AMPs are active against both bacterial and mammalian cells. The selectivity of AMPs for bacterial vs. mammalian cells is believed to be based on the differences in the chemical composition of the two cell membranes.^{2, 3} Bacterial cells contain a high percentage of negatively charged phospholipids while mammalian cells contain a much higher concentration of zwitterionic phospholipids.¹² Other differences also exist between the two including; membrane composition (sterols, lipopolysaccharide, peptidoglycan etc.)¹,

structure, transmembrane potential, and membrane polarizability. In addition to the differences between eukaryotic and prokaryotic cells the membranes surrounding different types of bacterial cells are also different. The lipid bilayer of Gram positive bacteria is covered by a porous layer of peptidoglycan, while the structure of Gram negative bacteria is more complex consisting of two lipid membranes containing lipopolysaccharides and porins.^{17 2} The outer membrane of mycobacterium is the most complex of the three, consisting of an additional very thick mycolate-rich outer coat which is very difficult to penetrate.

It is generally no longer accepted that AMPs are uniform and indiscriminant membrane detergents. As more information becomes available regarding the sophisticated and thematic structure-activity relationships underlying distinct mechanisms of action among AMPs, there will be a greater understanding of their likely multiple roles in antimicrobial host defense.¹ There is growing evidence in the literature that the selectivity and potency of a specific AMP is determined in a large measure by the chemical composition of the target membrane.⁸ Thus, it is reasonable to postulate that the membrane's physicochemical surface interactions with the physicochemical surface of the AMP defines the organism specific potency and selectivity.^{2, 8, 17, 18} As pointed out by Toke³, understanding how the physicochemical interactions between AMPs and the lipid composition of their target cells are important that they define organism potency and selectivity which is critical for the development of AMP derived drugs.

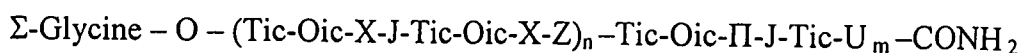
SUMMARY OF THE INVENTION

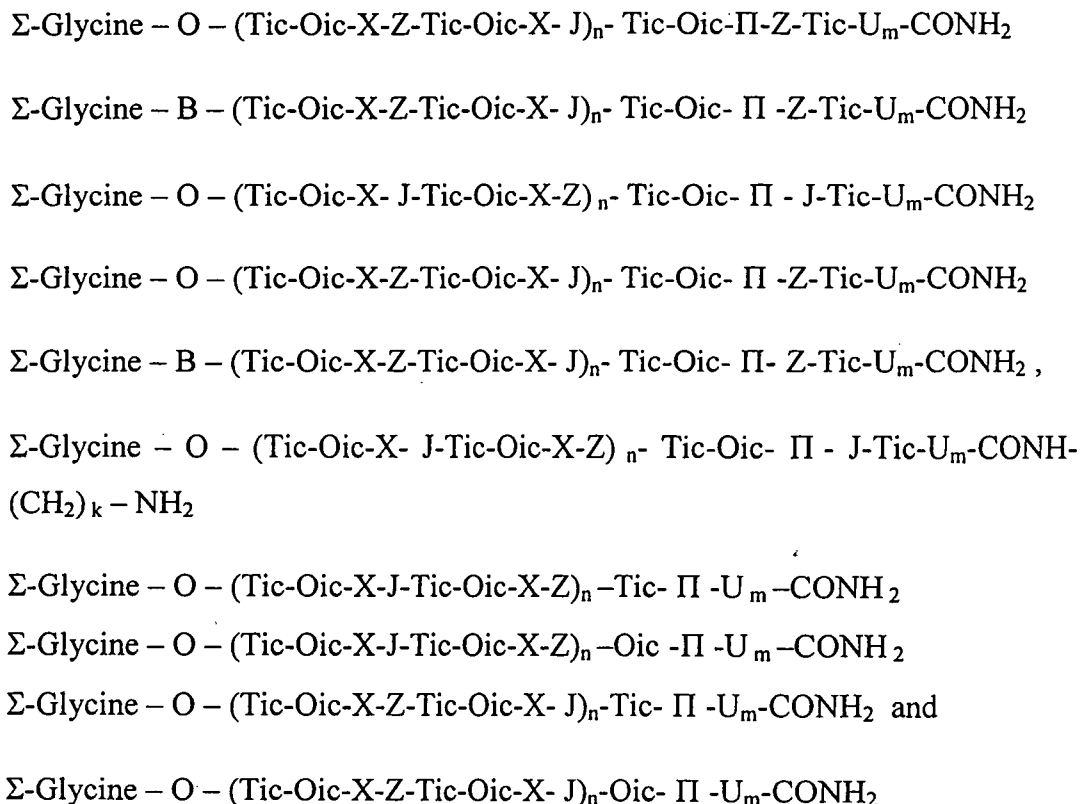
The evolution of drug resistant bacterial strains is one of the most critical problems facing modern medicine and requires the development of drugs that exhibit anti-bacterial activity via novel mechanism. Antimicrobial peptides (AMPs) interact differently with different bacterial strains (such as Gram positive, Gram negative and mycobacterium) based on the differing chemical composition of their respective cell membranes. The inventors have discovered that small changes in the structure and

physicochemical properties of the constituent amino acid residues can lead to major changes in the potency and selectivity of a particular AMP for a particular bacterial strain. Therefore, by selection and placement of natural and/or un-natural amino acid residues with specific physicochemical properties, the inventors have designed a new class of AMPs with increased potency and selectivity for one or more specific strains of bacteria.

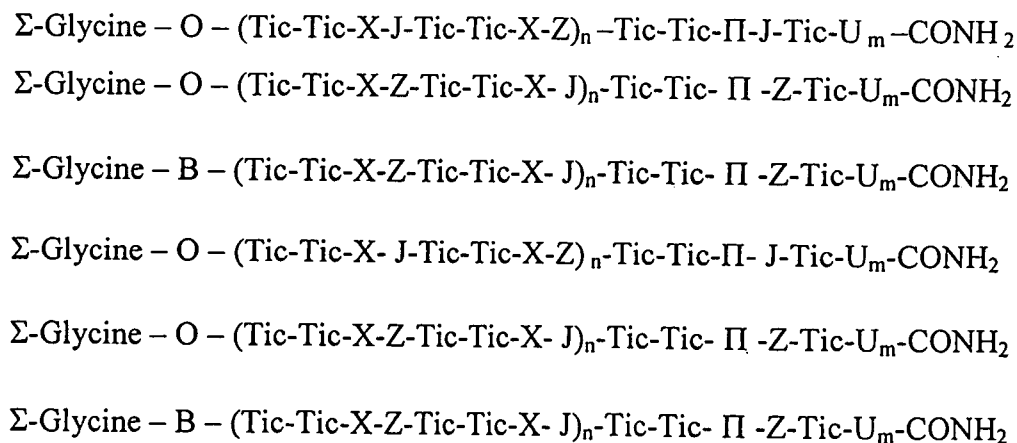
As a source of new drugs, the inventors have explored naturally occurring peptides that exhibit antimicrobial activity via membrane disruption. They have designed, synthesized and evaluated a new class of novel antimicrobial peptides containing un-natural amino acids, which AMPs exhibit increased potency and selectivity against Gram positive, Gram negative and Mycobacterium—and unexpectedly many of the new AMPs also exhibit reduced hemolytic activity. These new compounds were designed based on the electrostatic surface potential maps derived from the SDS and DPC micelle-bound conformations of (Ala^{8,13,18})magainin-2-amide, as described in more detail below. Un-natural amino acids were incorporated into the polypeptide backbone to control the structural and physicochemical properties of the peptides to introduce organism selectivity and potency. The inventors discovered that un-natural amino acid residues increase the resistance to proteolytic or enzymatic degradation, thus providing improved stability in biological systems over AMPs consisting of only natural amino acids. Such peptides may be referred to as peptidomimetic. The term "peptidomimetic" denotes a small protein-like chain synthetically designed to mimic a natural peptide, as for instance, where a natural peptide is modified to alter the peptide's properties. Typically, changes include those that will not occur naturally (such as altered backbones and the incorporation of non-natural amino acids).

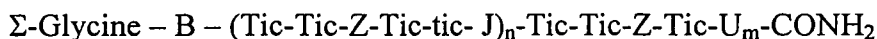
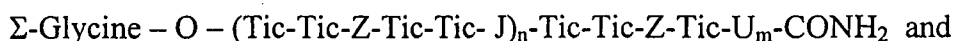
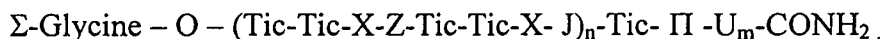
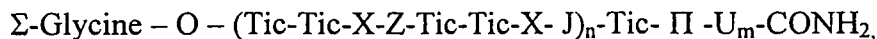
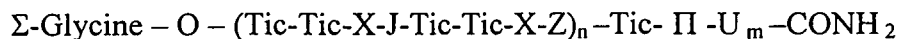
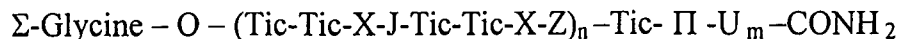
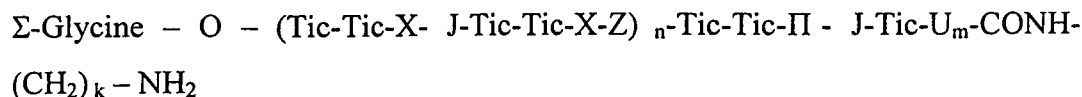
More particularly, the inventors discovered that a synthetic antimicrobial peptide analog having one of the following (referred to hereafter as General Formulae) were effective against at least one of Gram positive, Gram negative and Mycobacterium, and preferably (but not necessarily) exhibit reduced hemolytic activity.





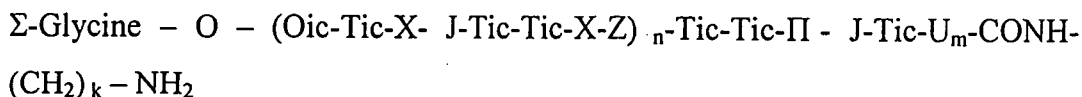
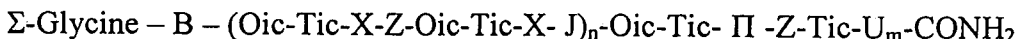
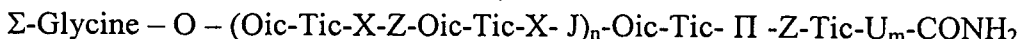
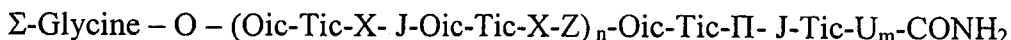
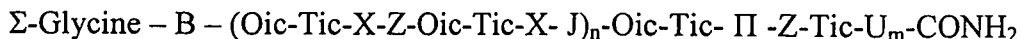
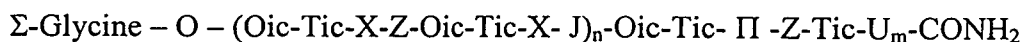
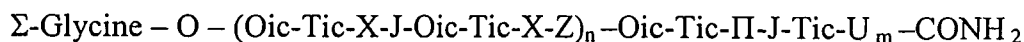
In addition, one preferred embodiment of the AMPs is encompassed by the following, which are referred to as the "Tic-Tic analogs". As shown below, these analogs exhibit greater selectivity for *Mycobacterium ranae*, compared to Gram positive and Gram negative bacteria.

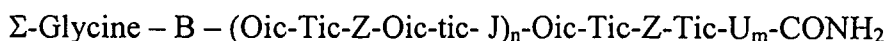
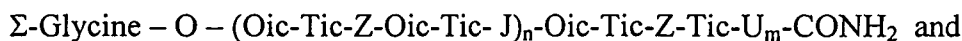
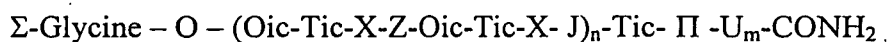
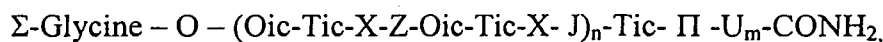
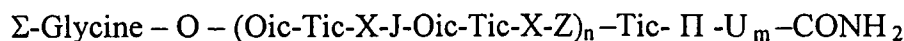
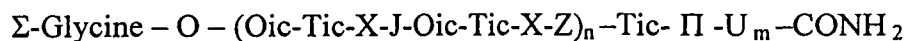




An example of a compound that falls within this set of formulae is Compound 59, which is described below.

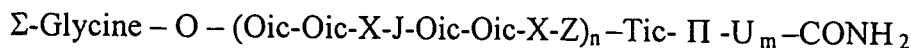
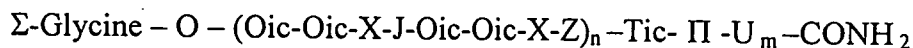
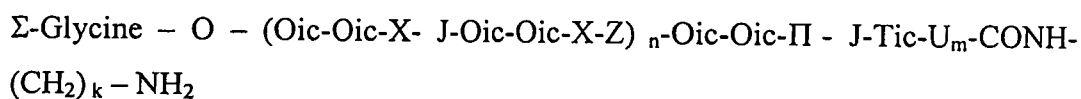
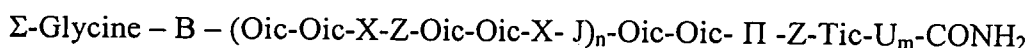
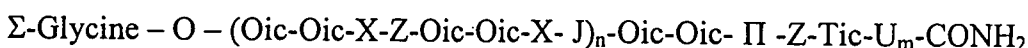
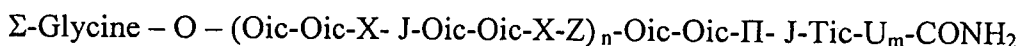
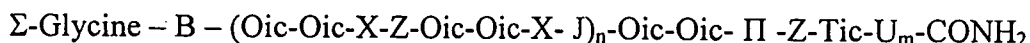
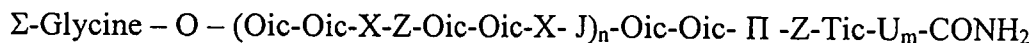
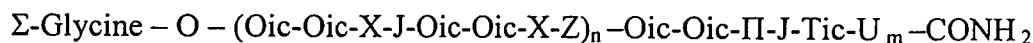
Another preferred embodiment of the AMPs is encompassed by the following formulae, which are referred to as the "Oic-Tic analogs". As shown below, these analogs exhibit greater selectivity for *Mycobacterium ranae*, compared to Gram positive and Gram negative bacteria.

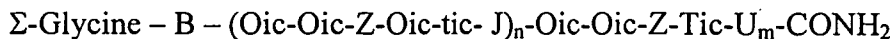
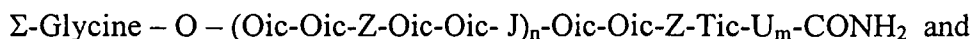
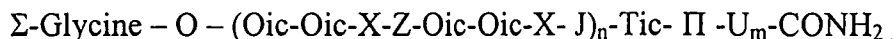
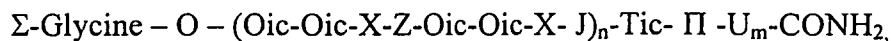




An example of a compound that falls within this set of formulae is Compound 61, which is described below.

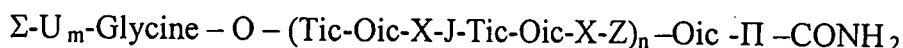
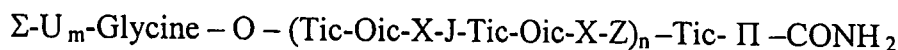
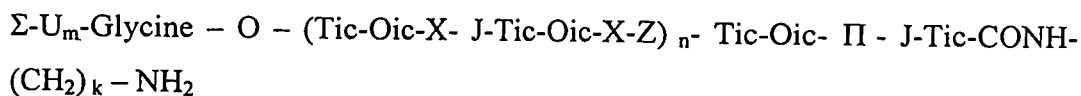
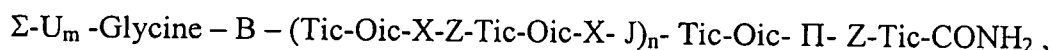
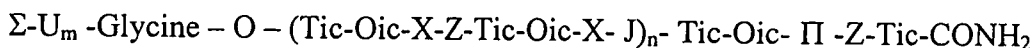
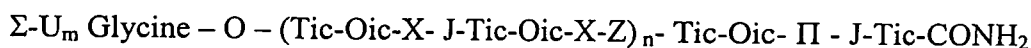
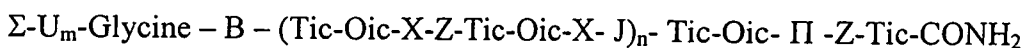
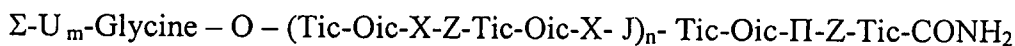
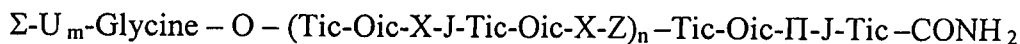
Another embodiment of the AMPs is encompassed by the following formulae, which are referred to as the "Oic-Oic analogs". These analogs may exhibit greater selectivity for *Mycobacterium ranae*, compared to Gram positive and Gram negative bacteria.

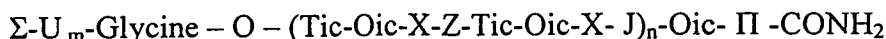
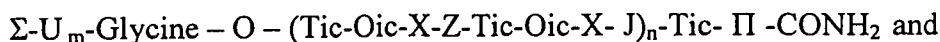




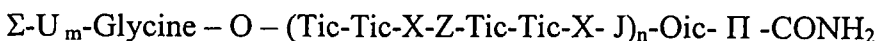
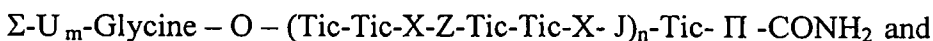
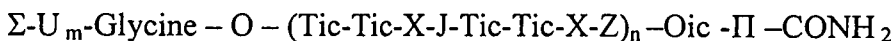
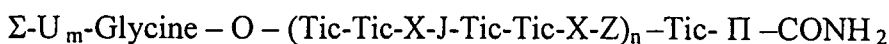
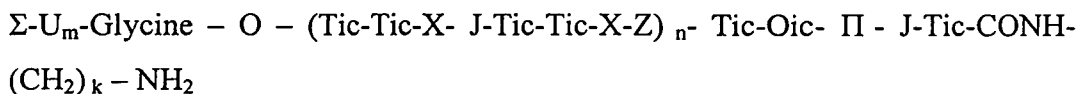
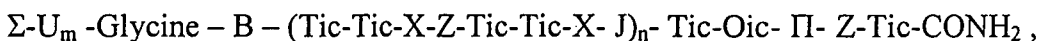
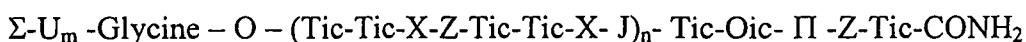
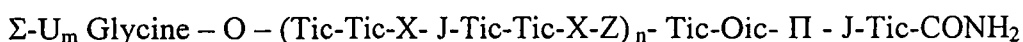
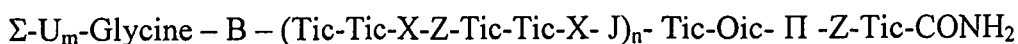
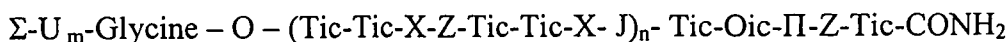
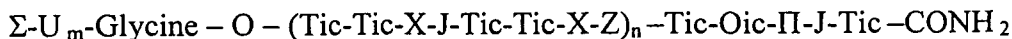
Another embodiment of the AMPs is encompassed by the following set of formulae, which have the positively charge residues (Lys, Arg etc.) at the N-terminus and not the C-terminus. For instance, Compound 63 is as follows: Ac-*KKKK*-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-CONH₂, and the “*KKKK*” in italics at the N-terminus shows the residues with a positive charge.

As shown below, these analogs exhibit greater selectivity for *Mycobacterium ranae*, compared to Gram positive and Gram negative bacteria.



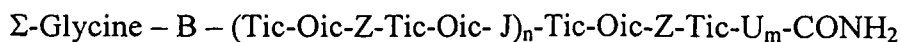
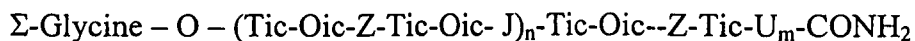


Another embodiment of the AMPs is encompassed by the following set of formulae, which is believed to have an especially high selectivity for Mycobacterium.



An example of a compound that falls within this set of is Compound 64, which is described below.

The following differ from the above in that they do not contain either spacer 1 or 2. However, as shown below, compounds having these still exhibit good activity against Gram positive, Gram negative, and especially mycobacterium, and may offer organism selectivity (see compounds below labeled, FKAB-1Ge, FKAB-1Gc and FKAB-1Gcl.) These are included within the General Formulae as this term is intended here.



For purposes of clarity, these two formulae which do not contain either spacer 1 or spacer 2 are sometimes referred to herein as “the reduced spacer”.

In these, Tic stands for tetrahydroisoquinolinecarboxylic acid, and Oic stands for octahydroindolecarboxylic acid. The Tic residue contains an aromatic ring, and Oic contains a non-aromatic ring which contributes to their hydrophobicity. The symbol “ Σ ” denotes one of acetyl, NH_2 , biotin, β -thienylalanine (Thi), cysteine, or Keyhole Limpet Haemocyanin (KLH) or BSA (Bovine Serum Albumin) (where acetyl or NH_2 are preferred). “U” is lysine, arginine, histidine, ornithine, 2,3-diaminopropionic acid (Dpr), 2,4-diaminobutanoic acid (Dab), 4-aminopiperidine-4-carboxylic acid (Apc4), or 3-aminopiperidine-3-carboxylic acid (Apc3) (where lysine, arginine, ornithine and 2,3-diaminopropionic acid are preferred). “X” is glycine, alanine, β -alanine, gamma-aminobutyric acid (Gaba), ϵ -aminohexanoic acid (Ahx), phenylglycine (Phg), 9-aminooctanoic acid (9-Aoa), 10-aminodecanoic acid (10Ada), 12-aminododecanoic acid (12-Adda), or 16-aminopalmitic acid (16-Apa). “J” is lysine, arginine, histidine, ornithine, 2,3-diaminopropionic acid (Dpr), or 2,4-diaminobutanoic acid (Dab). “Z” is phenylalanine, tyrosine, tryptophan, 4-fluorophenylalanine (Fpa), 4-chlorophenylalanine (Cph), 4-nitrophenylalanine (Nph), phenyl glycine (Phg), valine or isoleucine. “O” is phenylalanine, leucine, valine, isoleucine, norvaline, norleucine, norisoleucine, 4-Aminobutyric acid, piperidinic acid, 6-Aminocaproic acid, 2-Aminoheptanoic acid, 2-Aminoisobutyric acid, 3-Aminoisobutyric acid, 2-Aminopimelic acid, 2,4-Diaminobutyric acid, N-Ethylglycine, allo-Isoleucine, N-Methylglycine (or sarcosine), N-Methylisoleucine, or N-Methylvaline (where phenylalanine and leucine are preferred). “B” is lysine, arginine, histidine, ornithine, 2,3-diaminopropionic acid (Dpr), 2,4-diaminobutanoic acid (Dab), 4-aminopiperidine-4-carboxylic acid (Apc4), or 3-aminopiperidine-3-carboxylic acid (Apc3). “II” is glycine, alanine, β -alanine or gamma-aminobutyric acid (Gaba), or ϵ -Aminohexanoic acid (Ahx), with glycine or

β -alanine preferred. "n" is 1 to 4 repeating units (where 1 or 2 is preferred), "m" is 1 to 5 repeating units (where 3 or 4 is preferred), and "k" is 1 to 5 repeating units (where 2 or 3 is preferred).

All of the analogs described here are active against at least one strain of bacteria. These compounds have certain physicochemical properties that will result when these amino acid residues are combined together in the specified manner. The amino acid residues incorporated into these analogs are selected based on the following criteria. Amino acid residues used as Spacers 1 and 2 should exhibit hydrophobicity between 1.2 and -0.75 on the octanol scale (which scale is reported by Professor Stephen White at the University of California Irvine)¹⁹ The cationic amino acid residues should exhibit a hydrophobicity between 1.5 and 3.0 on the octanol scale. The hydrophobic amino acid residues should exhibit a hydrophobicity between -1.0 and -3.0 on the octanol scale. The general formulae are reasonably considered predictive of the antimicrobial activity, since the testing and results of them (as described below) were obtained from a large number of different peptides synthesized based on the general formulae where most variations were represented by at least one example. Further, these predictions were validated by the excellent results obtained through molecular modeling studies.

In simple terms, what is described and encompassed here are antimicrobial peptides comprising turn-inducing tetrahydroisoquinolinecarboxylic acid and octahydroindolecarboxylic acid (Tic-Oic) unit linked to a first spacer amino acid. (The exception to this is the reduced spacer, which lack the first and second spacers.) The first spacer amino acid is linked via an amide bond to an amino acid having a cationic side chain. (Figure 1A) The amino acid having a cationic side chain is linked to a second Tic-Oic unit which is linked to a second spacer amino acid, which second spacer amino acid is linked to a hydrophobic amino acid. Or the first spacer amino acid is linked via an amide bond to a hydrophobic amino acid. (Figure 1B) The hydrophobic amino acid is linked to a second Tic-Oic unit which is linked to a second spacer amino acid, which second spacer amino acid is linked to an amino acid having a cationic side chain. A combination of cationic and hydrophobic amino acid residues are required

for activity. The exact number and placement of these residues define the organism selectivity and hemolytic activity.

By "spacer" it is meant an amino acid residue separating a single Tic, or Oic residue or an Tic-Oic, Oic-Tic, Tic-Tic or Oic-Oic dipeptide unit from a cationic or hydrophobic residue. A "spacer" amino acid should not be electronically charged (cationic or anionic) nor should it be highly hydrophobic or highly hydrophilic. The role of the "spacer" is to provide conformational flexibility for the polypeptide backbone. In the General Formulae, "X" denotes the first and second spacers, that is, spacers 1 and 2. Spacer 1 and 2 can be any combination of two of the following amino acids. In addition spacer 1 and 2 can be the same amino acid (e.g. Gly).

List of possible amino acids for spacers 1 and 2

1. Gly
2. Ala
3. β -Ala
4. Gaba
5. e-Ahx (6-Ahx, 6-Aminohexanoic acid)
6. Phg (Phenylglycine)
7. 9-Aoa: (9-Aminooctanoic acid)
8. 10Ada: 10-Aminodecanoic acid
9. 12-Adda: 12-Aminododecanoic acid
10. 16-Apa (16-Aminopalmitic acid)

It is preferred that the first and second X have a length between 3.5 and 28.0 angstroms. Spacers 1 and 2 may be the same or different amino acids.

There may of course be additional spacers besides spacers 1 and 2. For instance, a third spacer might be present, as long as it is not electronically charged (cationic or anionic) or highly hydrophobic. It is noted that for spacers other than spacers 1 and 2, these should exhibit hydrophobicity between 1.2 and -0.75, and generally provide conformational flexibility for the backbone.

When the term "linked" is used, it is understood that all amino acids are linked together using amide bonds. This is the normal method of linking two amino acids

together by condensing the amine of amino acid with the carboxylic acid of another amino acid to form an amide bond.

The cationic amino acid, designated in the General Formulae as "B" and "U", may include the following.

List of possible cationic amino acids

1. Lys
2. Arg
3. His
4. Orn
5. Dpr (2,3-Diaminopropionic acid)
6. Dab (2,4-Diaminobutanoic acid)
7. Apc3(3-Aminopiperidine-3-carboxylic acid)
8. Apc4 (4-Aminopiperidine-4-carboxylic acid)

The cationic amino acid residues should exhibit hydrophobicity between 1.5 and 3.0 on the octanol scale.

The hydrophobic amino acid, designated in the General Formulae as "Z", may include the following.

List of possible hydrophobic amino acids

1. Phe
2. Leu
3. Tyr
4. Trp
5. Fpa(Fpa, 4-Fluorophenylalanine)
6. Cph (Cph, 4-Chlorophenylalanine)
7. Nph (Nph, 4-Nitrophenylalanine)
8. Phg (Phenyl Glycine)
9. Val
10. Ile
11. Nva (Norvaline)
12. Nle (Norleucine)
13. Norisoleucine
14. 4Abu (-Aminobutyric acid)
15. Piperidinic acid
16. Acp (6-Aminocaproic acid)

17. Ahe (2-Aminoheptanoic acid)
18. Aib (2-Aminoisobutyric acid)
19. β Aib (3-Aminoisobutyric acid)
20. Apm (2-Aminopimelic acid)
21. Dbu (2,4-Diaminobutyric acid)
22. EtGly (N-Ethylglycine)
23. alle (allo-Isoleucine)
24. MeGly (N-Methylglycine or sarcosine)
25. Melle (N-Methylisoleucine)
26. MeVal (N-Methylvaline)

The hydrophobic amino acid residues should exhibit hydrophobicity between -1.0 and -3.0 on the octanol scale.

For the reasons described below, it is preferred that the Tic and Oic when linked form a unit which induces a β -turn. As is known in the art, there are three types of β -turns that the Tic-Oic dipeptide can induce depending on the amino acid residues used for spacers 1 and 2. Type I- β -turn exhibits a backbone dihedral angles of -60, -30 for residue $i+1$ and -90, 0 for residue $i+2$. Type II- β -turn exhibits a backbone dihedral angles of -60, 120 for residue $i+1$ and 80, 0 for residue $i+2$. Type III- β -turn exhibits a backbone dihedral angles of -60, -30 for residue $i+1$ and -60, -30 for residue $i+2$. A type III β -turn is the basic single unit of a 3/10 helix. In addition a variation of the individual angles of ± 30 degrees is allowed within each structural class. Residues $i+1$ and $i+2$ are defined as residues 2 and 3 of the four amino acids composing a β -turn. Thus depending on the amino acids used as spacers 1 and 2 the peptide can either adopt back-to-back β -turns (these β -turns maybe Type I, Type II, Type III or any combination of the three) or it can adopt a 3/10 helical conformation on binding to the cell membrane. Thus, the AMPs described here can have Type I, Type II or Type III β -turns, or any combination of these.

It is further preferred that an antimicrobial peptide of one of these General Formulae in its secondary structure will include, when $n = 1$ or 2, at least three β -turns, and preferably five, and exhibits sufficient conformational flexibility to bind to the membrane of at least one of Gram positive bacteria, Gram negative bacteria or

Mycobacteria. A minimum of three back-to-back β -turns or three turns of a 3/10 helix are required to provide the amphipathic structure. If the number of β -turns is increased above 6 or 7 there is a higher probability that the analogs will exhibit higher hemolytic activity without a concurrent increase in antibacterial activity. (See results below for the analogs labeled WRFK-1 to WRFK-5.) It is preferred that these antimicrobial peptides exhibit cell-selective, membrane-disruptive antimicrobial activity against at least one of Gram positive bacteria, Gram negative bacteria or Mycobacteria—such as, for example, *Salmonella typhimurium*, *Staphylococcus aureus*, *Mycobacterium ranae* or *Bacillus subtilis*.

In a preferred embodiment, the antimicrobial peptides will exhibit less hemolytic activity than naturally occurring non-selective antimicrobial peptides. Of course, any decrease in hemolysis is advantageous over naturally occurring AMPs, such as melittin and pardaxin.³

It is noted that where the AMPs are used against an infection and are administered intravenously or orally, it is more important that the AMPs have reduced hemolytic activity. However, for topical applications, such as for wound treatment and the like, hemolytic activity is not a concern. Thus, especially where the AMPs are included in compositions to treat infections by topical application, it is not important that the AMPs have any decreased hemolytic activity at all.

This invention also contemplates compositions containing one or more of the antimicrobial peptides defined by the General Formulae. Where a particular bacterium is targeted for treatment, the composition may include at least one AMP that is effective against that bacterium. For instance, a composition to treat infection by Gram positive bacteria would contain at least one AMP that is effective against Gram positive bacteria. The same is true for Gram negative bacteria and mycobacteria, for which treatment antibiotic compositions can be prepared which include at least one AMP that is effective against that type of bacteria. On the other hand, where a broad-based antibiotic is desired, which may be effective to treat two or all three of Gram positive bacteria, Gram negative

bacteria or Mycobacteria, the composition may include multiple AMPs where each AMP is selected for its particular activity against one of these classes of bacteria—thus, the composition would include at least one AMP that is effective against Gram positive bacteria, at least one AMP that is effective against Gram negative bacteria, and at least one AMP that is effective against Mycobacteria.

Along those lines, compositions containing the AMPs defined by the General Formulae may also be useful to treat malaria infection. The inventors have shown anti-malarial activity similar to other antibiotic drugs. (Table 1)

Table 1. Anti-malarial activity of selected analogs

Peptide ID	IC ₅₀ * W2 (ug/mL)	IC ₅₀ * D6 (ug/mL)
WRFK-1	5.7	7.3
WRFK-2	6.9	7.2
WRFK-3	7.2	5.2
WRFK-4	6.5	7.8
WRFK-5	4.2	3.9

Plasmodium falciparum strains used D6 (CDC Sierra Leone, mefloquine resistant), W2 (CDC Indochina III chloroquine, quinine, pyrimethamine and sulfadoxine-resistant)

In addition, compositions containing the AMPs defined by the General Formulae may also be useful as antifungal agents against, for instance, such fungus as *Candida albicans* (which is the most prevalent fungal pathogen in humans) and *Cryptococcus neoformans* ²⁰, *Botrytis cinerea*, *Fusarium culmorum* and *Neurospora crassa* ²¹ and literature data supports this.

The compositions may include pharmaceutically acceptable adjuvants, stabilizers or carriers. For instance, the compound may be admixed with lactose, sucrose, starch powder, cellulose esters of alkanolic acids, cellulose alkyl ester, talc, stearic acid, magnesium stearate, magnesium oxide, sodium and calcium salts of phosphoric and sulphuric acids, gelatin, acacia, sodium alginate, polyvinyl-pyrrolidone and/or polyvinyl alcohol, and thus tableted or encapsulated for convenient administration. Alternatively, the compound may be dissolved in water, polyethylene glycol, propylene glycol, ethanol, corn oil, cotton seed oil, peanut oil, sesame oil, benzyl alcohol, sodium chloride and/or various buffers. Appropriate additives for the use as ointments, cremes or gels are for example paraffin, vaseline, natural waxes, starch cellulose, or polyethylenglycol. Other adjuvants and modes of administration are well and widely known in the pharmaceutical art. See the examples and description of U.S. Patent No. 6,730,326.

For instance, antibiotic compositions are encompassed here, which might include one or more of the novel AMPs described here, plus combinations of the antimicrobial peptides and other known antibiotic drugs such as ciprofloxacin, carbenicillin, nalidixic acid,²² amoxicillin, levofloxacin, cefuroxime and erythromycin²¹ additionally the use of imipenem, rifampicin and azithromycin²³, and the like.

Antibiotics can take the form of a pill, capsule, liquid (in aqueous solution), intravenous, topical cream or ointment, or any known method of administration, depending on the age, weight, health and life situation of a patient, and the type of bacteria/bacterium sought to be treated and stage of infection. For example, as a topical application the antimicrobial peptides of the General Formulae may be useful for treatment of impetigo, diabetic foot ulcer infections, catheter-related bloodstream infections, wound healing, burn healing, and acne. As examples of application in oral solution, the antimicrobial peptides may be useful to treat Gingivitis and mouth infections. As examples of parenteral use, the antimicrobial peptides may be useful to treat invasive fungal infections, lung infections in cystic fibrosis patients, systemic multi-resistant Gram positive bacterial infections, and pediatrics meningococemia. Another

useful application may be for treatment of biofilm infections associated with bone surgeries or artificial metallic implants. Another use may be for treatment of tuberculosis. These are just examples, not at all meant to be limiting, of the wide range of uses, forms and methods of application of the AMPs. Someone having ordinary skill in the area of antimicrobial peptides and antibiotics in general would readily be able to adapt the AMPs to the particular mode of administration and dosage that is appropriate to treat the ailment or condition desired.

In another embodiment, this invention includes methods for treating humans or mammals infected by at least one of Gram positive bacteria, Gram negative bacteria or Mycobacterium (such as, for example, *Salmonella typhimurium*, *Staphylococcus aureus*, *Mycobacterium ranae* or *Bacillus subtilis*). In a related embodiment, the invention includes methods for treating humans or mammals infected by certain select agents such as *Bacillus anthracis* and *Yersinia pestis* (the plague). (Generally speaking, to be considered effective to treat one or more of these bacteria, the AMP must have a minimum antimicrobial activity of 100 uM in-vitro. Such methods comprise the step of administering to a mammal suspected of infection by at least one of Gram positive bacteria, Gram negative bacteria or Mycobacteria a pharmaceutically effective amount of at least one of a synthetic antimicrobial peptide analog having a formula described above in the General Formulae, and a pharmaceutically acceptable adjuvant or carrier. For instance, an antibiotic composition may be used, such as is described above. The inventors have found that in the case of *Mycobacterium ranae*, antimicrobial peptides that include the Tic-Tic analog (such as for instance, compound 59, FKAB-1Gg2, described below) and the Oic-Tic analog (such as for instance, compound 61, FKAB-1Gg1, described below), are particularly selective and effective. In the case of *Bacillus anthracis* and *Yersinia pestis* (the plague), it is preferred that the synthetic antimicrobial peptide analog be chosen from the group consisting of compounds 24, 34, 38, 44, 45, 52-57, 59, and 60 (as described below). Especially preferred for *Bacillus anthracis* are compounds 24, 34, 38, 44, 45, 53, 57, 59 and 60. Especially preferred for *Yersinia pestis* are compounds 34, 44, 45, 52, 53, 54, 55, 56, 59 and 60.

The antimicrobial peptide may be administered by any appropriate methods, as would be understood by someone having skill in this art—such as topical, intravenous, infusion, and oral administration. Someone skilled in this art would be able to readily determine the appropriate dosage for each patient, depending on the age, weight, health and life situation of the patient, and of course the specific type and stage of the infection. In addition, the choice of adjuvant may influence the effectiveness of a dose, and someone having ordinary skill in this art would be able to determine the type of administration and dosage. Standard dosage amounts and schedules for antibiotics would apply for this invention as well. For example, for intravenous administration, the dosage regimen is preferably 1-25 mg/kg per day; for oral administration, the dosage regimen is preferably 1-25 mg/kg per day.

The results of the inventors' analysis of the success of these antimicrobial peptides as a new class of potent broad spectrum antibacterials with relatively low hemolytic activity are detailed below, but some highlights may be summarized as follows. The inventors' reference compound for the ultimate development of their unnatural AMPs was the naturally occurring antimicrobial peptide magainin I. Magainin I exhibited MIC activity against *Salmonella typhimurium* of 30 μ M and was not active in vitro against *Staphylococcus aureus* ME/GM/TC resistant bacteria at concentrations as high as 100 μ M. The AMP compounds discovered and described herein exhibited a ten fold increase in potency against *Salmonella typhimurium* and at least a 33 fold increase in potency against *Staphylococcus aureus* ME/GM/TC resistant bacteria. In addition the inventors have discovered that small structural modifications will lead to analogs that will exhibit high organism selectivity. This overall approach represents a paradigm shift from the current drug discovery approaches involving antimicrobial peptides.

For instance, one compound designated FKAB-1Gw exhibited the highest in vitro selectivity for *Salmonella typhimurium* with a 10-fold selectivity over *Staphylococcus aureus* ME/GM/TC resistant bacteria and a 33-fold selectivity over *Mycobacterium ranae*. Compound FKAB-1Gd3 exhibited a 3-fold selectivity over *Salmonella typhimurium* and a 10-fold selectivity over *Staphylococcus aureus* ME/GM/TC resistant

while compound FKAB-1Go exhibited a 10-fold selectivity over *Salmonella typhimurium* and a 3-fold selectivity over *Staphylococcus aureus* ME/GM/TC resistant. These three compounds were the most selective analogs for *Mycobacterium ranae*. Compounds WRFK-2 and WRFK-4 exhibit 10-fold or greater selectivity for *Staphylococcus aureus* ME/GM/TC resistant bacteria versus *Salmonella typhimurium* and *Mycobacterium ranae* however they exhibit 100% hemolytic activity.

Overall, antimicrobial peptides of the General Formulae were shown to exhibit significant potency and selectivity against Gram positive, Gram negative and/or Mycobacterium, and many also exhibited the advantageous property of at least some level of reduced hemolytic activity.

This invention also encompasses a Quantitative Structure Activity Relationship (QSAR) modeling system utilizing mathematical equations that calculate the biological activity of any peptide sequence against *Staphylococcus aureus* (MRSA) and *Mycobacterium ranae*. The inventors developed highly predictive 3D-QSAR models for the antimicrobial peptides described herein containing unnatural amino acids, which models employ specific mathematical equations. In particular, they have discovered a set of 5-15 physicochemical properties that are most important for manifestation of antimicrobial activity against *Staphylococcus aureus* or *Mycobacterium ranae*. Using these equations and the list of physicochemical properties, someone having ordinary skill in this art can use them to guide the design and synthesis of other antimicrobial peptides.

As described herein, these AMPs of the invention exhibit extremely potent activity against *Salmonella typhimurium*, *Staphylococcus aureus*, *Mycobacterium ranae*, and *Bacillus subtilis*. Employing the recently reported bioactive conformer mining methodology, the inventors have computed highly predictive models for *Staphylococcus aureus* (SA) and *Mycobacterium ranae* (MR) with non-validated r^2 of 0.987 and 0.998 respectively. The value r^2 is the correlation coefficient, and the best attainable value is 1.00, so the models with a r^2 value of 0.99 indicates an excellent correlation of the predictive value of the model. The SA and MR models performed well on internal

validation tests, with leave-one-out correlation q^2_{LOO} of 0.839 and 0.997 and leave-10%-out correlation q^2_{L100} of 0.875 and 0.537 respectively. As is well known, cross-validation is a standard statistical technique.

Internal validation (cross-validation) tests of the selected QSAR models were performed at two levels. Both of the models showed $q^2_{LOO} > 0.83$ for the leave-one-out (LOO) cross-validation tests. For the leave-10%-out or leave-three-out (L100) cross-validation tests, *SA* model showed q^2_{L100} of 0.875, whereas *MR* model showed q^2_{L100} values of 0.537. The propensity for this chance correlation is assessed by the randomization test where the dependent variables (bioactivity) are randomly reassigned to different compounds and a new regression model is recomputed, with the process being repeated several times. If the statistical data of these randomized models are comparable to the computed QSAR model, then the QSAR model is not predictive and the number of observations is insufficient. The inventors performed randomization tests of ninety-nine trials each at 99% confidence level for *SA* and *MR* QSAR models. None of the random r values were found to be larger than the non-random r values for either the *SA* or the *MR* models. The mean random r value for the *SA* model was 0.572 ($r^2 = 0.327$), and for the *MR* model was 0.617 ($r^2 = 0.380$). This indicates that the *SA* and *MR* QSAR models are not obtained by chance.

Therefore, this embodiment of the invention entails methods for predicting physicochemical and bioactivity properties (especially antimicrobial activity) of a peptide sequence (especially but not limited to peptides containing non-natural amino acids such as the AMPs described herein) against *SA* and/or *MR*.

The equation with four significant digits, for *SA* is as follows : *SA* predicted activity = $[(-1.4959 \times \text{"Fcharge"}) + (0.0098 \times \text{"dipole-mag"}) + (0.0140 \times \text{"Jurs-SASA"}) + (0.0023 \times \text{"Jurs-PPSA-1"}) + (0.1876 \times \text{"Jurs-PNSA-1"}) + (0.0022 \times \text{"Jurs-PNSA-2"}) + (0.00037 \times \text{"Jurs-DPSA-2"}) + (0.0015 \times \text{"Jurs-DPSA-3"}) + (438.251 \times \text{"Jurs-FPSA-1"}) + (267.258 \times \text{"Jurs-FPSA-3"}) + (120.432 \times \text{"Jurs-FNSA-3"}) - (715.316 \times \text{"Jurs-RPCG"}) -$

$(12.8649 \times \text{"Jurs-RPCS"}) - (0.0658 \times \text{"Jurs-TASA"}) - (125.513 \times \text{"Jurs-RPSA"}) +$
 $(125.513 \times \text{"Jurs-RASA"}) - (183.99 \times \text{"density"}) + (1.0340 \times \text{"Hbond acceptor"}) +$
 $(0.0395 \times \text{"Hbond donor"}) - (0.3069 \times \text{"Rotlbonds"}) + (0.1148 \times \text{"AlogP"}) - (0.10004 \times$
 $\text{"RadOfGyration"}) - 225.589].$

The equation with five significant digits (more preferred) for SA is as follows:
 SA predicted activity = $[(-1.49592 \times \text{"Fcharge"}) + (0.00981 \times \text{"dipole-mag"}) + (0.01399$
 $\times \text{"Jurs-SASA"}) + (0.00233 \times \text{"Jurs-PPSA-1"}) + (0.18765 \times \text{"Jurs-PNSA-1"}) + (0.00217$
 $\times \text{"Jurs-PNSA-2"}) + (0.00037 \times \text{"Jurs-DPSA-2"}) + (0.00150 \times \text{"Jurs-DPSA-3"}) +$
 $(438.251 \times \text{"Jurs-FPSA-1"}) + (267.258 \times \text{"Jurs-FPSA-3"}) + (120.432 \times \text{"Jurs-FNSA-3"}) -$
 $(715.316 \times \text{"Jurs-RPCG"}) - (12.8649 \times \text{"Jurs-RPCS"}) - (0.06575 \times \text{"Jurs-TASA"}) -$
 $(125.513 \times \text{"Jurs-RPSA"}) + (125.513 \times \text{"Jurs-RASA"}) - (183.99 \times \text{"density"}) + (1.03397$
 $\times \text{"Hbond acceptor"}) + (0.03947 \times \text{"Hbond donor"}) - (0.30686 \times \text{"Rotlbonds"}) + (0.11481$
 $\times \text{"AlogP"}) - (0.10004 \times \text{"RadOfGyration"}) - 225.589].$

The most preferred equation for SA is as follows: SA predicted activity = $[(-$
 $1.49592 \times \text{"Fcharge"}) + (0.0098147 \times \text{"dipole-mag"}) + (0.013993 \times \text{"Jurs-SASA"}) +$
 $(0.00233 \times \text{"Jurs-PPSA-1"}) + (0.187647 \times \text{"Jurs-PNSA-1"}) + (0.0021686 \times \text{"Jurs-PNSA-}$
 $2") + (0.00036919 \times \text{"Jurs-DPSA-2"}) + (0.0015025 \times \text{"Jurs-DPSA-3"}) + (438.251 \times$
 $\text{"Jurs-FPSA-1"}) + (267.258 \times \text{"Jurs-FPSA-3"}) + (120.432 \times \text{"Jurs-FNSA-3"}) - (715.316 \times$
 $\text{"Jurs-RPCG"}) - 12.8649 \times \text{"Jurs-RPCS"}) - (0.065752 \times \text{"Jurs-TASA"}) - (125.513 \times$
 $\text{"Jurs-RPSA"}) + (125.513 \times \text{"Jurs-RASA"}) - (183.99 \times \text{"density"}) + (1.03397 \times \text{"Hbond$
 $\text{acceptor"}) + (0.039473 \times \text{"Hbond donor"}) - (0.306856 \times \text{"Rotlbonds"}) + (0.114808 \times$
 $\text{"AlogP"}) - (0.10004 \times \text{"RadOfGyration"}) - 225.589].$

This embodiment of the invention covers the novel equation, as well as a synthetic peptide with bioactivity against SA satisfying the equation. Preferably, the synthetic peptide satisfies at least four terms of the equation. (A term is defined as the product of the QSAR coefficient (e.g. "438.251") and Descriptor (e.g., "Jurs-FPSA-1") shown in parenthesis e.g. $(438.251 \times \text{"Jurs-FPSA-1"})$.) As another way to define the synthetic peptides of this invention, the synthetic peptide may have at least 4, more preferably at least 5, more preferably at least 6, more preferably at least 7, etc., up to 15,

where it is most preferable to have at least 15 of the following physicochemical properties:

Jurs-FPSA-1, with a 29.347 [$\text{\AA}^2$] (area units Angstroms²),
density – 16.010 is grams/cubic centimeters;
Jurs-TASA – 14,762 [$\text{\AA}^2$];
Jurs-PNSA-1 – 10.540 [$\text{\AA}^2$];
Jurs-RASA – 7,886 [$\text{\AA}^2$];
Jurs-SASA – 4.120 [$\text{\AA}^2$];
Jurs-DPSA-2 – 3.093 [$\text{\AA}^2$];
Jurs –PNSA-2 – 2.911 [$\text{\AA}^2$];
Jurs-RPSA – 2.492;
Rotlbonds – 2.164;
Hbond acceptor – 1.910;
Jurs-FPSA-3 – 1.709;
Fcharge – 0.742;
Jurs-RPCG – 0.726;
Jurs-PPSA-1 – 0.555;
Jurs-FNSA-3 – 0.426;
Dipole-mag – 0.162;
RadOfGyration – 0.127;
Jurs-RPCS – 0.126;
Hbond donor – 0.113;
Jurs-DPSA-3 – 0.053;
and AlogP – 0.026.

These numbers represent the respective percentages of each property, indicating the respective contribution toward overall bioactivity. Definitions of the descriptors are given in Table 2 and other portions below. We note that for some of the descriptors (e.g., density, Jurs –PNSA-2, Jurs-RPSA, Rotlbonds, Fcharge, Jurs-RPCG, Jurs-FNSA-3, RadOfGyration, Jurs-RPCS, and AlogP) the corresponding percentage numbers may

appear as a negative number, with a “-“ sign preceding it. This is acceptable and understood in the art of QSAR modeling, and the descriptor may be defined either way.

Further details regarding how these properties were characterized and the data obtained are provided below.

Regarding MR, the equation with four significant digits for MR is as follows:
 MR predicted activity = $[(-0.0084 \times \text{"conformer energy"}) + (2.0576 \times \text{"Fcharge"}) + (0.00005 \times \text{"Apol"}) + (0.0061 \times \text{"dipole-mag"}) - (0.0239 \times \text{"Jurs-PPSA-1"}) - (0.0083 \times \text{"Jurs-PNSA-1"}) + (0.00005 \times \text{"Jurs-PPSA-2"}) + (0.00019 \times \text{"Jurs-PNSA-2"}) - (18.282 \times \text{"Jurs-FPSA-1"}) + (13.321 \times \text{"Jurs-FNSA-3"}) - (8.4684 \times \text{"Jurs-RPCG"}) + (66.6262 \times \text{"Jurs-RNCG"}) + (0.0529 \times \text{"Jurs-TPSA"}) - (96.9761 \times \text{"Jurs-RPSA"}) + (96.9761 \times \text{"Jurs-RASA"}) - (127.577 \times \text{"density"}) + (0.7687 \times \text{"Hbond acceptor"}) - (0.4983 \times \text{"Hbond donor"}) - (0.0608 \times \text{"Rotlbonds"}) - (0.0758 \times \text{"AlogP"}) + (0.3378 \times \text{"RadOfGyration"}) + 110.841]$.

The equation with five significant digits (preferred) for MR is as follows: MR predicted activity = $[(-0.00836 \times \text{"conformer energy"}) + (2.05758 \times \text{"Fcharge"}) + (0.000053 \times \text{"Apol"}) + (0.00614 \times \text{"dipole-mag"}) - (0.02394 \times \text{"Jurs-PPSA-1"}) - (0.00825 \times \text{"Jurs-PNSA-1"}) + (0.000055 \times \text{"Jurs-PPSA-2"}) + (0.00019 \times \text{"Jurs-PNSA-2"}) - (18.282 \times \text{"Jurs-FPSA-1"}) + (13.321 \times \text{"Jurs-FNSA-3"}) - (8.46841 \times \text{"Jurs-RPCG"}) + (66.6262 \times \text{"Jurs-RNCG"}) + (0.05289 \times \text{"Jurs-TPSA"}) - (96.9761 \times \text{"Jurs-RPSA"}) + (96.9761 \times \text{"Jurs-RASA"}) - (127.577 \times \text{"density"}) + (0.768698 \times \text{"Hbond acceptor"}) - (0.49828 \times \text{"Hbond donor"}) - (0.06076 \times \text{"Rotlbonds"}) - (0.07576 \times \text{"AlogP"}) + (0.33784 \times \text{"RadOfGyration"}) + 110.841]$.

The most preferred equation for MR is as follows: MR predicted activity = $[(-0.0083585 \times \text{"conformer energy"}) + (2.05758 \times \text{"Fcharge"}) + (5.3259\text{e-}05 \times \text{"Apol"}) + (0.0061422 \times \text{"dipole-mag"}) - (0.023941 \times \text{"Jurs-PPSA-1"}) - (0.008252 \times \text{"Jurs-PNSA-1"}) + (5.5381\text{e-}05 \times \text{"Jurs-PPSA-2"}) + (0.00018566 \times \text{"Jurs-PNSA-2"}) - (18.282 \times \text{"Jurs-FPSA-1"}) + (13.321 \times \text{"Jurs-FNSA-3"}) - (8.46841 \times \text{"Jurs-RPCG"}) + (66.6262 \times \text{"Jurs-RNCG"}) + (0.052889 \times \text{"Jurs-TPSA"}) - (96.9761 \times \text{"Jurs-RPSA"}) + (96.9761 \times \text{"Jurs-RASA"}) - (127.577 \times \text{"density"}) + (0.768698 \times \text{"Hbond acceptor"}) - (0.498282 \times \text{"Hbond donor"}) - (0.06076 \times \text{"Rotlbonds"}) - (0.07576 \times \text{"AlogP"}) + (0.33784 \times \text{"RadOfGyration"}) + 110.841]$.

donor”) - (0.060764 × “Rotlbonds”) - (0.075759 × “AlogP”) + (0.337835 × “RadOfGyration”) + 110.841].

This embodiment of the invention covers the novel equation, as well as a synthetic peptide with bioactivity against MR satisfying the equation. Preferably, the synthetic peptide satisfies at least four terms of the equation. (A term is defined as the product of the QSAR coefficient and Descriptor shown in parenthesis e.g. (438.251 × “Jurs-FPSA-1”).) As another way to define the synthetic peptides of this invention, the synthetic peptide may have at least 4, more preferably at least 5, more preferably at least 6, more preferably at least 7, etc., up to 15, where it is most preferable to have at least 15 of the following physicochemical properties:

Density – 30.784;

Jurs-RASA – 16.827;

Jurs-PPSA-1 – 15.494;

Jurs-TPSA – 10.218;

Jurs-RPSA – 5.444;

Hbond donor – 3.905;

Hbond acceptor – 3.729;

Jurs-FPSA-1 – 3.409;

Fcharge – 2.892;

Jurs-PNSA-1 – 1.244;

RadOfGyration – 1.164;

Rotlbonds – 1.156;

Apol – 1.148 ;

Jurs-PPSA-2 – 1.016;

Jurs-PNSA-2 – -0.632;

Jurs-RNCG – 0.400;

Dipole-mag – 0.298;

Jurs-FNSA-3 – 0.127;

AlogP – 0.051;

Conformer Energy – 0.037;

Jurs-RPCG – -0.024; and

Jurs-DPSA-2 – 0.00.

These numbers represent the respective percentages of each property, indicating the respective contribution toward overall bioactivity. Definitions of the descriptors are given in Table 2 and other portions below. We note that for some of the descriptors (e.g., density, Jurs-PPSA-1, Jurs-RPSA, Jurs-FPSA-1, Jurs-PNSA-1, Rotlbonds, Jurs-PNSA-2, Jurs-FNSA-3, Jurs-RPCG, and Hbond donor) the corresponding percentage numbers may appear as a negative number, with a “-” sign preceding it. This is acceptable and understood in the art of QSAR modeling, and the descriptor may be defined either way.

Further details regarding how these properties were characterized and the data obtained are provided below.

In addition, this embodiment of the invention covers methods for predicting whether a peptide is bioactive against *Staphylococcus aureus* (SA) or *Mycobacterium ranae*, comprising the step of applying the respective mathematical equations described herein. These equations provide the blue print for designing potent antimicrobial peptides. Any peptide may be tested, but it is generally desirable to choose a peptide sequence which is thought to have the major 5 to 12 physicochemical properties. Then the conformational models of these peptides are computed, and then lastly is computed the physicochemical properties of those peptide conformations that fall within 0 to 10 Kcals of the peptide global minimum. Those peptides that have conformations which show potent predicted bioactivity are the ones that are most likely to be potent AMPs.

Put a different way, the invention encompasses methods for determining whether a synthetic peptide has an overall structure such that it is bioactive against either *Staphylococcus aureus* (SA) or *Mycobacterium ranae* (MR). The methods apply the respective mathematical equations described herein, and may employ any standard molecular modeling software. The basic steps in applying the equation are as follows:

- i) Build the peptide sequence and minimize it using standard molecular mechanics. As an example of molecular mechanics, see http://en.wikipedia.org/wiki/Molecular_mechanics.
- ii) Compute the conformational model for the peptide using standard Monte Carlo or Molecular Dynamics conformational search algorithms (The conformational model is collection of energy minimized conformations within 20 Kcals/mol of the global minimum conformation. The global minimum conformation is the conformation with the least energy value of all the conformations.) As an example of Monte Carlo algorithm, see http://en.wikipedia.org/wiki/Monte_carlo_algorithm. A pool of conformers includes perhaps thousands of "unique" conformations, which is considered in the art to be an exhaustive conformational search.
- iii) From all the conformations select the most "extended shaped" conformation (the extended shaped conformation would have the maximum measurement of its backbone when measured from head to tail) that is within 5 Kcals/mole energy range of the global minimum conformer.
- iv) Align all conformers with the extended shaped selected conformer backbone as template structure.
- v) Compute all the physicochemical (descriptor) properties for all the aligned conformers. These descriptor values are plugged into the equations of step iv) to calculate predicted bioactivity.
- vi) Compute the predicted SA and / or MR bioactivity using the relevant QSAR equations, and the descriptor values calculated in step v).

By minimization, it is meant a well-known procedure using computer software by which the shape of the compound is incrementally changed and potential energy calculated. If the energy is lower than the previous shape then the new shape is accepted, and further incremental changes tried until such time that the potential energy is minimized to the extent possible. In computer simulations of compounds, the compound is represented as atoms and bonds, and then the compound has potential energy associates

with it by virtue of motion of matter at any temperature above absolute zero. This potential energy value is what will differ between different shapes or conformations of the compound. For example, if a compound has two hydroxyl O-H moieties and if these are placed such that the two oxygen atoms are very close to each other, then there will be a repelling force between them which will effectively strain the compound—this will be manifested in the high potential energy of that conformer/shape of the compound.

Thus, in one embodiment it may be determined whether a synthetic peptide is bioactive (preferably at least showing activity of 100microMolar or less) against *Staphylococcus aureus* (SA), using a method comprising the steps of:

i) determining the shape of a peptide that has minimum potential energy of the peptide;

ii) computing the conformational model for the peptide using standard Monte Carlo or molecular dynamics conformational search algorithms, so as to generate a pool of peptide conformations that are within 20Kcals/mol energy range of the global minimum conformation;

iii) selecting from the peptide conformations of step ii) the conformation having the maximum measurement of its backbone when measured from head to tail, which conformation is within five Kcals/mole energy range of the global minimum conformer;

iv) aligning all conformations of step ii) with the selected conformation of step iii), wherein the selected conformation is used as a template structure;

v) determining the physicochemical properties for all the aligned conformations, wherein the physicochemical properties determined are conformer energy, Fcharge, dipole-mag, Jurs-SASA, Jurs-PPSA-1, Jurs-PNSA-1, Jurs-PNSA-2, Jurs-DPSA-2, Jurs-DPSA-3, Jurs-FPSA-1, Jurs-FPSA-3, Jurs-FNSA-3, Jurs-RPCG, Jurs-RPCS, Jurs-TASA, Jurs-RPSA, Jurs-RASA, density, Hbond acceptor, Hbond donor, Rotlbonds, AlogP, and RadOfGyration; and

vi) applying a mathematical equation to each aligned conformation peptide, to determine whether the synthetic peptide is bioactive against *Mycobacterium ranae* (MR), which mathematical equation is: SA bioactivity equals satisfaction of at least four of the

following terms: $[(-1.49592 \times \text{"Fcharge"}) + (0.0098147 \times \text{"dipole-mag"}) + (0.013993 \times \text{"Jurs-SASA"}) + (0.00233 \times \text{"Jurs-PPSA-1"}) + (0.187647 \times \text{"Jurs-PNSA-1"}) + (0.0021686 \times \text{"Jurs-PNSA-2"}) + (0.00036919 \times \text{"Jurs-DPSA-2"}) + (0.0015025 \times \text{"Jurs-DPSA-3"}) + (438.251 \times \text{"Jurs-FPSA-1"}) + (267.258 \times \text{"Jurs-FPSA-3"}) + (120.432 \times \text{"Jurs-FNSA-3"}) - (715.316 \times \text{"Jurs-RPCG"}) - 12.8649 \times \text{"Jurs-RPCS"}) - (0.065752 \times \text{"Jurs-TASA"}) - (125.513 \times \text{"Jurs-RPSA"}) + (125.513 \times \text{"Jurs-RASA"}) - (183.99 \times \text{"density"}) + (1.03397 \times \text{"Hbond acceptor"}) + (0.039473 \times \text{"Hbond donor"}) - (0.306856 \times \text{"Rotlbonds"}) + (0.114808 \times \text{"AlogP"}) - (0.10004 \times \text{"RadOfGyration"}) - 225.589.$

Similalry, to determine whether a synthetic peptide is bioactive (preferably at least showing activity of 100microMolar or less) against Mycobacterium ranae (MR), a method may comprise the steps of:

- i) determining the shape of a peptide that has minimum potential energy of the peptide;
- ii) computing the conformational model for the peptide using standard Monte Carlo or molecular dynamics conformational search algorithms, so as to generate a pool of peptide conformations that are within 20Kcals/mol energy range of the global minimum conformation;
- iii) selecting from the peptide conformations of step ii) the conformation having the maximum measurement of its backbone when measured from head to tail, which conformation is within five Kcals/mole energy range of the global minimum conformer;
- iv) aligning all conformations of step ii) with the selected conformation of step iii), wherein the selected comformation is used as a template structure;
- v) determining the physicochemical properties for all the aligned conformations, wherein the physicochemical properties determined are conformer energy, Fcharge, Apol, dipole-mag, Jurs-PPSA-1, Jurs-PNSA-1, Jurs-PPSA-2, Jurs-PNSA-2, Jurs-FPSA-1, Jurs-FNSA-3, Jurs-RPCG, Jurs-RNCG, Jurs-TPSA, Jurs-RPSA, Jurs-RASA, density, Hbond acceptor, Hbond donor, Rotlbonds, AlogP, and RadOfGyration; and
- vi) applying a mathematical equation to each aligned conformation peptide, to determine whether the synthetic peptide is bioactive against Mycobacterium ranae (MR),

which mathematical equation is: MR bioactivity equals satisfaction of at least four of the following terms: $[(-0.0083585 \times \text{"conformer energy"}) + (2.05758 \times \text{"Fcharge"}) + (5.3259\text{e-}05 \times \text{"Apol"}) + (0.0061422 \times \text{"dipole-mag"}) - (0.023941 \times \text{"Jurs-PPSA-1"}) - (0.008252 \times \text{"Jurs-PNSA-1"}) + (5.5381\text{e-}05 \times \text{"Jurs-PPSA-2"}) + (0.00018566 \times \text{"Jurs-PNSA-2"}) - (18.282 \times \text{"Jurs-FPSA-1"}) + (13.321 \times \text{"Jurs-FNSA-3"}) - (8.46841 \times \text{"Jurs-RPCG"}) + (66.6262 \times \text{"Jurs-RNCG"}) + (0.052889 \times \text{"Jurs-TPSA"}) - (96.9761 \times \text{"Jurs-RPSA"}) + (96.9761 \times \text{"Jurs-RASA"}) - (127.577 \times \text{"density"}) + (0.768698 \times \text{"Hbond acceptor"}) - (0.498282 \times \text{"Hbond donor"}) - (0.060764 \times \text{"Rotlbonds"}) - (0.075759 \times \text{"AlogP"}) + (0.337835 \times \text{"RadOfGyration"}) + 110.841]$.

Further details regarding how these equations are applied and bioactivity determined, and the data obtained, are provided below.

Table 2. List of trial descriptors used for the QSAR model.

Descriptor Symbol	Descriptor definition
LogP	n-Octanol/water partition coefficient
Fh2o	The desolvation free energy for water
Foct	The desolvation free energy for n-octanol
AlogP98	The partition coefficient computed on atom types reported by Ghose et al ³⁵
AlogP	The partition coefficient computed on atom types reported by Ghose et al ³⁴
MR	The molar refractivity is computed based on refractive index molecular weight (MW)
MolRef	The molar refractivity is computed based on the atom-types with additive contributions reported by Ghose et al ^{34,35}
The thirty Jurs descriptors based on partial charges mapped on surface area were reported by Stanton et al ³⁶	
Jurs-SASA	The total molecular solvent accessible surface.

Jurs-PPSA-1	The sum of the solvent-accessible surface area of all partially positively charged atoms.
Jurs-PNSA-1	The sum of the solvent-accessible surface area of all partially negatively charged atoms.
Jurs-DPSA-1	The differential positively charged surface area is the difference between Jurs-PPSA-1 and Jurs-PNSA-1.
Jurs-PPSA-2	The partial positive solvent-accessible surface area times the total positive charge.
Jurs-PNSA-2	The partial negative solvent-accessible surface area times the total negative charge.
Jurs-DPSA-2	The differential positively charged surface area is the difference between Jurs-PPSA-2 and Jurs-PNSA-2.
Jurs-PPSA-3	The sum of the products of solvent accessible surface area and partial charge for all positively charged atoms.
Jurs-PNSA-3	The sum of the products of solvent accessible surface areas and partial charge for all negatively charged atoms.
Jurs-DPSA-3	The differential positively charged surface area is the difference between Jurs-PPSA-3 and Jurs-PNSA-3.
Jurs-FPSA-1	The fractionally charged surface area is obtained by dividing Jurs-PPSA-1 by total molecular solvent-accessible surface area (Jurs-SASA).
Jurs-FNSA-1	The fractionally charged surface area is obtained by dividing Jurs-PNSA-1 by total molecular solvent-accessible surface area (Jurs-SASA).
Jurs-FPSA-2	The fractionally charged surface area is obtained by dividing Jurs-PPSA-2 by total molecular solvent-accessible surface area (Jurs-SASA).
Jurs-FNSA-2	The fractionally charged surface area is obtained by dividing Jurs-PNSA-2 by total molecular solvent-accessible surface area (Jurs-SASA).
Jurs-FPSA-3,	The fractionally charged surface area is obtained by dividing Jurs-PPSA-3 by total molecular solvent-accessible surface area (Jurs-SASA).

Jurs-FNSA-3	The fractionally charged surface area is obtained by dividing Jurs-PNSA-3 by total molecular solvent-accessible surface area (Jurs-SASA).
Jurs-WPSA-1	The surface-weighted charged partial surface area is obtained by multiplying the descriptor Jurs-PPSA-1 by SASA and dividing by 1000.
Jurs-WNSA-1	The surface-weighted charged partial surface area is obtained by multiplying the descriptor Jurs-PNSA-1 by SASA and dividing by 1000.
Jurs-WPSA-2	The surface-weighted charged partial surface area is obtained by multiplying the descriptor Jurs-PPSA-2 by SASA and dividing by 1000.
Jurs-WNSA-2	The surface-weighted charged partial surface area is obtained by multiplying the descriptor Jurs-PNSA-2 by SASA and dividing by 1000.
Jurs-WPSA-3	The surface-weighted charged partial surface area is obtained by multiplying the descriptor Jurs-PPSA-3 by SASA and dividing by 1000.
Jurs-WNSA-3	The surface-weighted charged partial surface area is obtained by multiplying the descriptor Jurs-PNSA-3 by SASA and dividing by 1000.
Jurs-RPCG	The relative positive charge is computed by dividing the charge of the most positive atom by the total positive charge.
Jurs-RNCG	The relative negative charge computed by dividing the charge of the most negative atom by the total negative charge.
Jurs-RPCS	The relative positive charge surface area is computed as the solvent-accessible surface area of the most positive atom divided by RPCG.
Jurs-RNCS	The relative negative charge surface area is obtained by dividing the solvent-accessible surface area of the most negative atom divided by RNCG.
Jurs-TASA	The total hydrophobic surface area is computed as the sum of the solvent-accessible surface area of atoms with absolute partial charge less than 0.2.
Jurs-TPSA	The total polar surface area is the sum of the solvent-accessible surface areas of atom with absolute partial charges greater than or

	equal 0.2.
Jurs-RASA	The relative hydrophobic surface area, is computed by dividing TASA by SASA.
Jurs-RPSA	The relative polar surface area is obtained by dividing TPSA by SASA.
Density	Density is defined as the ratio of molecular weight to molecular volume
Vm	Molecular volume
PMI-Mag	The magnitude of the principal moments of inertia about the principal axes of the conformers as described by Hill ³⁷
Dipole-Mag	The magnitude of the molecular dipole moment.
Energy	'Energy' gives the conformational energy
Fcharge	The formal charge
H-bond Acceptor	Number of hydrogen bond acceptors
H-bond Donor	Number of hydrogen bond donors
Rotlbonds	Number of rotatable bonds
ChiralCenters	Number of chiral centers
RadOfGyration	The radius of gyration ³⁸
Area	The van der waals surface area
Apol	Sum of atomic polarizabilities ³⁹

BRIEF DESCRIPTION OF THE FIGURES

Figure 1A and 1B. A diagrammatic representation of the basic skeleton units of AMPs developed in the laboratory. By varying the length of spacer 1 the distance between the turn-inducing Tic-Oic dipeptide unit (enclosed in the dotted line in the figures) and the positive charge as well as the distance and angle (conformational flexibility) between the two turn-inducing units are changed. Varying the length of

spacer 2, (spacer 1 and spacer 2 may or may not be the same) the distance between the turn-inducing unit and the hydrophobic residue as well as the distance and angle between the two turn-inducing units are changed. These modifications affect all of the physicochemical properties as well as overall conformational flexibility.

Figure 2. The amide and aromatic region of the 600 MHz ^1H spectra of two peptides bound to SDS and DPC micelles. Spectrum A is the anti-bacterial peptide FKAB-1G bound to DPC micelles and spectrum B is the same peptide bound to SDS micelles. Spectrum C is the inactive peptide FKAB-4B bound to DPC micelles and spectrum D is the same peptide bound to SDS micelles. Micelle concentrations 100 mM in 150 mM sodium acetate buffer, pH= 4.05.

Figure 3. The electrostatic surface potential map of the active analogs FKAB-1G (activity against *Salmonella typhimurium* -10 μM , *Staphylococcus aureus* ME/GM/TC resistant- 3 μM *Mycobacterium ranae*-10 μM) clearly shows that the electrostatic surface potential is located on one face of the molecule (Figure 3B) while the other face is electrostatically neutral (Figure 3A). Thus the compound is highly amphipathic. Blue color indicates a positive charge, Red indicates a negative charge and white indicates a neutral electric charge.

Figure 4. The electrostatic surface potential map for the much less active analog FKAB-1Gf (activity against *Salmonella typhimurium* -100 μM , *Staphylococcus aureus* ME/GM/TC resistant- IN ACTIVE, *Mycobacterium ranae*-100 μM) shows the four sides or faces of FKAB-1Gf, clearly there is an even distribution of charge over the entire surface of the molecule. Figure 4A shows the east face, Figure 4B shows the north face, Figure 4C shows the west face, and Figure 4D shows the south face. The molecule is therefore not amphipathic. Blue color indicates a positive charge, Red indicates a negative charge and white indicates a neutral electric charge.

Figure 5. The effect of incorporation of the negatively charged penta-peptide (Glu-Leu-Met-Asn-Ser) found at the C-terminus of the magainins at both the C and N

terminus is shown by the electrostatic potential map of the completely inactive analog FKAB-4 is shown. Figure 4A shows the east face, Figure 4B shows the north face, Figure 4C shows the west face, and Figure 4D shows the south face. This Figure indicates that the in active analogs is neither highly charged or amphipathic. Blue color indicates a positive charge, Red indicates a negative charge and white indicates a neutral electric charge.

Figure 6. Time course of the wound healing in mouse cutaneous injury model. Test substances were administered topically once daily for ten consecutive days. The wound closure (%) and the wound half-closure time (CT50) were determined and One-way ANOVA followed by Dunnett's test was applied for comparison between treated and its corresponding vehicle groups on days 3, 5, 7, 9 and 11. Data provided by MDS Pharma Services.

Figure 7 shows the SA QSAR model with observed bioactivity versus the predicted bioactivity.

Figure 8 shows the MR QSAR model with observed bioactivity versus the predicted bioactivity.

Figure 9 shows the non- polar face of AMPs *Staphylococcus aureus* FKAB-1G, FKAB-1Go, FKAB-1Gb, FKAB-1Gd, and FKAB-1Gg.

Figure 10 shows the polar face of AMPs *Staphylococcus aureus* FKAB-1G, FKAB-1Go, FKAB-1Gb, FKAB-1Gd, and FKAB-1Gg.

Figure 11 shows the non- polar face of AMPs *Mycobacterium ranae* FKAB-1Ge, FKAB-1Gj, FKAB-1Ggl, and FKAB-1Gfl.

Figure 12 shows the polar face of AMPs *Mycobacterium ranae* FKAB-1Ge, FKAB-1Gj, FKAB-1Ggl, and FKAB-1Gfl.

Figure 13 shows the hydrophobic polar face of AMPs *Mycobacterium ranae* FKAB-1Ge, FKAB-1Gj, FKAB-1Gg1, and FKAB-1Gf1.

Figure 14 shows the 180 ° opposite (from Figure 13) hydrophobic face of AMPs *Mycobacterium ranae* FKAB-1Ge, FKAB-1Gj, FKAB-1Gg1, and FKAB-1Gf1.

Figure 15 shows the survival rate of mice against *Streptococcus pneumonia* (gram- positive), when tested with five compounds. Series 1 = control group; series 2 = compound 25; series 3 = compound 38; series 4 = compound 44; series 5 = compound 46; series 6 = compound 24.

Figure 16 shows the survival rate of mice against *Salmonella typhimurium* (gram-negative), when tested with five compounds. Series 1 = control group; series 2 = compound 25; series 3 = compound 38; series 4 = compound 44; series 5 = compound 46; series 6 = compound 24.

Figure 17 shows calculated “bio-active conformers” for the analogs with the deletion of either the Tic or Oic residue indicate that these analogs are extended and do not include a helical or β -turn structure. The Tic-Oic dipeptide turn inducing unit is shown in green. The cationic residues are shown in dark blue. Hydrophobic residues are shown in red. Spacers A and B are shown in light blue.

Figure 18 shows the calculated “bio-active” conformers of the analogs containing various length amino acid spacers in position A and B indicate that these compounds adopt a helical or β -turn conformation. The Tic-Oic dipeptide turn inducing unit is shown in green. The cationic residues are shown in dark blue. Hydrophobic residues are shown in red. Spacers A and B are shown in light blue.

Figure 19A is a top down view into the hexagonal pore form of SA peptidoglycan outer layer showing a highly charged polar surface. 8B and 8C are views from inside of the pore looking at two internal faces of the pore. Figures 19B shows a view looking

toward the highly charged polar face, while Figure 19C shows a view looking at the relatively non-polar opposite face. Color Coding: blue indicates positive potential, red indicates negative potential and white indicates neutral potential.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Antimicrobial Peptides

To develop effective synthetic AMPs, the inventors selected analogs of the magainin family of host defense peptides because these peptides are active against Gram positive and negative bacteria, fungi and protozoa while exhibiting little mammalian cell toxicity.²⁴ The interactions of the magainins^{25, 26} with membrane models have been extensively investigated resulting in the characterization of the magainins as well defined α -helical amphipathic cell-selective membrane-disruptors.^{16, 18, 19}

The inventors previously reported two-dimensional NMR and molecular modeling.²⁷ Investigations conducted in their laboratory indicated that (Ala^{8,13,18})magainin-2-amide bound to dodecylphosphocholine (DPC) micelles adopts a α -helical structure involving residues 2 to 16 with the four C-terminal residues converging to a loose β -turn like structure. While (Ala^{8,13,18})magainin-2-amide bound to sodium dodecylsulfate (SDS) micelles adopts a α -helical structure involving residues 7 to 18 with the C- and N-terminal residues exhibiting a great deal of conformational flexibility. The observation of an AMP adopting slightly different conformations on binding to SDS and DPC micelles was also reported by Hancock and co-workers²⁸ for the antimicrobial peptide indolicidin. The most plausible explanation for this observation is that different non-covalent (electrostatic and hydrophobic) interactions are occurring between the peptide's surface and the two micelle surfaces.

Based on previous research into peptide-micelle interactions, the inventors concluded electrostatic interactions are responsible for peptide-micelle binding while hydrophobic interactions are responsible for inducing a stable secondary structure onto the peptide.^{29, 30} The inventors observed that the relative position in three-dimensional

space of each of the multiple positive charges on the peptide to the hydrophobic residues controls the allowable conformational changes.³⁰ Therefore electrostatic interactions between the polar head groups of the micelle and the cationic side chains of the peptides define the positions along the peptide backbone where the helical structures begin and end.

Electrostatic surface potential maps for each conformation were calculated and indicated that the surface electron density of these peptides are highly conformational dependent. This observation lead to the hypothesis that the three-dimensional physicochemical surface properties of the membrane of a bacterial cell interacts with the three-dimensional physicochemical properties of the AMP as it approaches the surface of the cell. This interaction induces a conformational change onto the polypeptide backbone of the AMP in order to maximize attractive interactions and to minimize repulsive interactions between the two moieties. The results of the inventors' investigation indicate that hydrophobic interactions are the major contributors in stabilizing the induced helical structure of the micelle-bound peptides.

The inventors chose (Ala^{8,13,18})magainin-2-amide to design a novel class of AMPs since it had different physicochemical surface properties of the SDS and DPC micelle-bound conformations. These synthetic AMP analogs contain both natural and un-natural amino acids that induce a semi-rigid conformation to the peptide backbone thus controlling the three-dimensional physiochemical properties of the peptide. In particular, the two un-natural amino acids Tic (tetrahydroisoquinolinecarboxylic acid) and Oic (octahydroindolecarboxylic acid) are used to induce an amphiathic structure.

It is noted that Kyle et al. reported using NMR and molecular modeling methods that the dipeptide Tic-Oic when placed in positions $i+1$ and $i+2$ of a four amino acid sequence induced a β -turn.³¹ The work of Kyle et al. was limited to using a single Tic-Oic dipeptide to induce a β -turn conformation exclusively at the C-terminus of bradykinin antagonists which are naturally occurring peptides—quite distinct from the un-natural AMPs described here which are custom tailored synthetic peptides. The logic used by Kyle and co-workers was to force the C-terminus to adopt a conformation

avored by the bradykinin B₁ receptor. Their work did not involve the use of multiple Tic-Oic dipeptides, spacers or the other well defined and ordered disposition of other key components to interact with cell membranes to induce specific 3D physicochemical parameters onto the polypeptide backbone. Further, as is well known, bradykinin does not exhibit antibacterial activity.

However, the inventors discovered that placement of multiple Tic-Oic units connected via two amino acid spacers with defined properties of charge and hydrophobicity will result in peptides with well defined physiochemical properties and these peptides will still have sufficient conformational flexibility to allow interactions with membranes with different physicochemical properties to induce a “new” stable conformation onto the AMP on binding to the membrane. As noted above, a “spacer” amino acid should not be electronically charged (cationic or anionic) nor should it be highly hydrophobic. Spacers 1 and 2 should exhibit hydrophobicity between 1.2 and -0.75 on the octanol scale reported by Professor Stephen White at the University of California Irvine.¹⁹ The role of “spacer 1 and 2” is to provide conformational flexibility for the polypeptide backbone. The cationic amino acid residues should exhibit hydrophobicity between 1.5 and 3.0 on the octanol scale. The hydrophobic amino acid residues should exhibit hydrophobicity between -1.0 and -3.0 on the octanol scale.

The basic polypeptide skeleton of the new AMPs is given in Figure 1. This skeleton (Figure 1A) begins with a turn-inducing Tic-Oic unit coupled to a spacer amino acid followed by an amino acid with a cationic side chain. This is followed with another Tic-Oic unit coupled to a spacer followed by a hydrophobic amino acid residue. Or this skeleton (Figure 1B) begins with a turn-inducing Tic-Oic unit coupled to a spacer amino acid followed by a hydrophobic amino acid. This is followed with another Tic-Oic unit coupled to a spacer followed by an amino acid residue with a cationic side chain.

Figure 1A and 1B also illustrate the inter-relationship between the basic units and the interdependence of distances and angles. This basic unit is repeated to obtain the desired peptide length.³²

To confirm that these AMPs have sufficient structural flexibility to undergo significant conformational changes on interacting with membranes, their interactions with SDS and DPC micelles was observed by NMR.³² The effect of binding to DPC and SDS micelles is illustrated in Figure 2, which shows the amide and aromatic region of the 600 MHz ¹H spectra of two peptides bound to SDS and DPC micelles. Spectrum A is the anti-bacterial peptide designated as FKAB-1G bound to DPC micelles and spectrum B is the same peptide bound to SDS micelles. Clearly these two spectra are very different and the most likely explanation for this observation is that the peptides exist in two different conformations. The broadening in the resonances of the FKAB-1G bound to SDS micelles, particularly the aromatic resonances indicates restricted motion of the phenyl rings which is consistent with a "tighter" binding to the micelle. At the bottom of Figure 2 are the spectra of the inactive analog FKAB-4B bound to DPC (spectrum C) and SDS (spectrum D) micelles. Again these spectra are different, indicating that the peptide exists in two different conformations. However the line-widths of both spectra are narrower than those observed for FKAB-1G indicating that even though FKAB-4B binds to both micelles it has a greater degree of molecular flexibility.

A number of new AMPs have been synthesized within the general formulae given above, and the amino acid sequences of some of them are listed in Table 3.

Table 3. Amino acid sequences for novel antimicrobial peptides synthesized

Peptide ID Peptide # Amino acid sequence

WRFK-1	1	NH ₂ -GKGL-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GKR-CONH ₂
WRFK-2	2	NH ₂ -GKGL-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-Oic-GKR-CONH ₂
WRFK-3	3	NH ₂ -GKGL-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-

		Oic-GLR-CONH ₂
WRFK-4	4	NH ₂ -GKGL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GKR-CONH ₂
WRFK-5	5	NH ₂ -GKGL-Tic-Oic-FK-Tic-Oic-KF-Tic-Oic-FK-Tic-Oic-KF-Tic-Oic-FK-Tic-Oic-FKR-CONH ₂
FKAB-1F	24	NH ₂ -KL-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-Oic-KR-CONH ₂
FKAB-1G	25	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH ₂
FKAB-1H	26	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH-CH ₂ -CH ₂ -NH ₂
FKAB-1L	27	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH-CH ₂ -CH ₂ -CH ₂ -NH ₂
FKAB-1Ga	28	NH ₂ --GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH ₂
FKAB-1Gb	29	NH ₂ --KL-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH ₂
FKAB-1Gc	30	Ac-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-KKKK-CONH ₂
FKAB-1Gd	31	Ac-Gaba-F-Tic-Oic-Gaba-K-Tic-Oic-Gaba-F-Tic-Oic-Gaba-K-Tic-KKKK-CONH ₂
FKAB-1Ge	32	Ac-G-Tic-Oic-K-Tic-Oic-G-Tic-Oic-K-Tic-KKKK-CONH ₂
FKAB-1Gf	33	Ac-GF-Oic-GK-Oic-GF-Oic-GKKKKK-CONH ₂
FKAB-1Gg	34	Ac-GF-Tic-GK-Tic-GF-Tic-GK-Tic-KKKK-CONH ₂
FKAB-1Ggl	35	Ac-GF-Tic-G-GK-Tic-G-GF-Tic-G-GK-Tic-KKKK-CONH ₂
FKAB-1Gfl	36	Ac-GF-G-Oic-GK-G-Oic-GF-G-Oic-GK-G-KKKK-CONH ₂
FKAB-1Gh	37	Ac-GF-F-Oic-GK-F-Oic-GF-F-Oic-GK-F-KKKK-CONH ₂
FKAB-1Gdl	38	Ac-βAla-F-Tic-Oic-βAla-K-Tic-Oic-βAla-F-Tic-Oic-βAla-K-Tic-KKKK-CONH ₂
FKAB-1Gd2	39	Ac-Ahx-F-Tic-Oic-Ahx-K-Tic-Oic-Ahx-F-Tic-Oic-Ahx-K-Tic-KKKK-CONH ₂
FKAB-1Gcl	40	Ac-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-KKKKKK-CONH ₂
FKAB-1Gi	41	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKKKK-CONH ₂
FKAB-1Gd3	42	Ac-Gaba-F-Tic-Oic-Gaba-K-Tic-Oic-Gaba-F-Tic-Oic-Gaba-K-Tic-KKKKKK-CONH ₂
FKAB-1Gj	43	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Orn-Orn-Orn-Orn-CONH ₂

FKAB-1Go	44	Ac-G-Fpa-Tic-Oic-GK-Tic-Oic-G-Fpa-Tic-Oic-GK-Tic-KKKK-CONH ₂
FKAB-1Gp	45	Ac-GF-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-Orn-Orn-Orn-Orn-CONH ₂
FKAB-1Gl	46	Biotin-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH ₂
FKAB-1Gs	47	Ac-GF-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-Dpr-DprDpr-Dpr-CONH ₂
FBAB-1Gw	48	Ac-βAla-Fpa-Tic-Oic-βAla-Dpr-Tic-Oic-βAla-Fpa-Tic-Oic-βAla-Dpr-Tic-Dpr-Dpr-Dpr-Dpr-CONH ₂
FKAB-1G2	49	Ac-G-dF-Tic-Oic-GK-Tic-Oic-G dF-Tic-Oic-GK-Tic-KKKK-CONH ₂
FKAB-1G3	50	Ac-GF-Tic-Oic-G-dK-Tic-Oic-GF-Tic-Oic-G-dK-Tic-KKKK-CONH ₂
FKAB-1Go2	51	Ac-G-Nph-Tic-Oic-GK-Tic-Oic-G-Nph-Tic-Oic-GK-Tic-KKKK-CONH ₂
FKAB-1G-βAla	52	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-βAla-KKKK-CONH ₂
FKAB-1G-Gaba	53	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Gaba-KKKK-CONH ₂
FKAB-1G-Ahx	54	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Ahx-KKKK-CONH ₂
FKAB-1Gz	55	Ac-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Dab-Dab-Dab-Dab-CONH ₂
FKAB-1G-Thi	56	Thi-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH ₂
FKAB-1G-Trp	57	Ac-GF-Tic-Oic-GW-Tic-Oic-GF-Tic-Oic-GW-Tic-KKKK-CONH ₂
FKAB-1Gx-R2	58	Ac-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-RRRR-CONH ₂
FKAB-1Gg2	59	Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH ₂
FKAB-1Go1	60	Ac-G-Cph-Tic-Oic-GK-Tic-Oic-G-Cph-Tic-Oic-GK-Tic-KKKK-CONH ₂
FKABB-1G1	61	Ac-GF-Oic-Tic-GK-Oic-Tic-GF-Oic-Tic-GK-Tic-KKKK-CONH ₂
FKAB-1Gv	62	Ac-βAla-Fpa-Tic-Oic-βAla-K-Tic-Oic-βAla-Fpa-Tic-Oic-βAla-K-Tic-Dpr-Dpr-Dpr-Dpr-CONH ₂
FBAB-1Gq	63	Ac-KKKK-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-CONH ₂
	64	Ac-KKKK-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-CONH ₂

Additional amino acid sequences, exemplary of the general formulae, for novel AMPs include the following:

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂
 (NH₂)₄ -(K)₂-K-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-
 CONH₂
 Ac-G-Fpa-Tic-Oic-G-Dpr-Tic-Oic-G-Fpa-Tic-Oic-G-Dpr-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Gaba-KKKK-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Ahx-KKKK-CONH₂
 Ac-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Dab-Dab-Dab-Dab-CONH₂
 Ac-GF-Tic-Oic-G-Tic-Oic-GF-Tic-Oic-G-Tic-G-KKKK-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dab-Dab-Dab-Dab-CONH₂
 (NH₂)₄-(Orn)₂-Orn-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-
 Orn-Tic-
 CONH₂
 Thi-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂
 Ac-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-RRRR-CONH₂
 Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH₂
 Ac-GF-Oic-Oic-GK-Oic-Oic-GF-Oic-Oic-GK-Oic-KKKK-CONH₂,
 Cys-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂,
 (NH₂)₄-(Dpr)₂-Dpr-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-
 Dpr-Tic-
 CONH₂, and
 (NH₂)₄-(Dab)₂-Dab-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-
 Dab-Tic-CONH₂.

As noted above, in the General Formulae the term "X" denotes the first and second spacers, that is, spacers 1 and 2, which may or may not be the same amino acid. The Table 4 below shows molecular modeling that relates the length of spacer 1 and spacer 2 to anti-bacterial activity. The data are summarized below.

5 Table 4.—Spacer 1 and 2 inter-residue distance data

AMP	SPACER 1	SPACER 2	Distance from Oic to J	Distance from Oic to Z	<i>Salmonella</i> <i>typhimurium</i>	<i>Staphylococcus</i> <i>aureus</i> ME/GMTC resistant	<i>Mycobacterium</i> <i>ranæ</i>	<i>Bacillus</i> <i>subtilis</i>	% hemol- ysis
FKAB -1G	Gly	Gly	5.86	5.96	10 μ M	3 μ M	10 μ M	1 μ M	14%
FKAB -1Gc	no spacer	no spacer	3.96	3.89	10 μ M	3 μ M	30 μ M	1 μ M	86.80 %
FKAB -1Gd	Gaba	Gaba	7.74	9.5	10 μ M	100 μ M	10 μ M	1 μ M	10.80 %
FKAB -1Gd1	β -Ala	β -Ala	8.13	7.66	10 μ M	10 μ M	1 μ M	1 μ M	24.40 %
FKAB -1Gd2	Ahx	Ahx	9.26	8.9	10 μ M	10 μ M	3 μ M	1 μ M	44.70 %

Spacers 1 and 2 in FKAB-1G are both Gly residues. Thus there is only one carbon atom between the amide nitrogen atom and the carbonyl carbon atom of the amino acid residue. Compound FKAB-1Gd1 spacers 1 and 2 are both β -Ala residues containing a two carbon spacer. This modification had little or no effect on the activity against all four bacterial strains; however, hemolytic activity increased to 25%. Compound FKAB-1Gd spacers 1 and 2 are both the amino acid Gaba containing a three carbon spacer. This modification had no effect *Salmonella typhimurium*, or *Mycobacterium ranae*. However, the activity against *Staphylococcus aureus* ME/GM/TC resistant bacteria was dramatically reduced from 3 to 100 μ M. Hemolytic activity was approximately equal to compound FKAB-1G. Compound FKAB-1Gd2 spacers 1 and 2 are both 6-aminohexonic acid (an un-natural amino acid) containing a five carbon spacer. This modification had little or no effect on the activity against *Salmonella typhimurium* or *Staphylococcus aureus* ME/GM/TC resistant bacteria or *Mycobacterium ranae*. However the hemolytic activity increased to 45%.

The final modification to spacers 1 and 2 was to delete this residue all together in compound FKAB-1Gc. The deletion of both spacers 1 and 2 resulted in no change in the activity against *Salmonella typhimurium* and *Staphylococcus aureus* ME/GM/TC resistant bacteria with a very small increase in the activity against *Mycobacterium ranae*. The hemolytic activity however dramatically increased to 87%, making this compound the most toxic to red blood cells of the series tested.

This data is indicative that spacers 1 and 2 play a role in determining the conformational flexibility of these compounds and the resulting type of β -turn adopted by the Tic-Oic dipeptide unit. Based on the observation that compound FKAB-1Gc exhibits the highest hemolytic activity, coupled with the observation in the literature that helical character favors hemolytic activity, the inventors believe that the absence of spacers 1 and 2 reduces the conformational freedom of the peptide and induces a 3/10 helical conformation on to the peptide facilitating the binding to the membrane of red blood cells. The other spacers seem to exhibit, as one would expect, greater conformational

freedom allowing the peptide to adopt different conformations on interaction with red blood cells.

As far as anti-bacterial activity is concerned, none of the spacers had a great effect except for Gaba, (FKAB-1Gd) which had a dramatic effect by reducing the activity 33 fold against *Staphylococcus aureus* ME/GM/TC resistant bacteria. This result implies that this spacer makes it more difficult for compound FKAB-1Gd to adapt under the influence of the physicochemical properties of the *Staphylococcus aureus* cell membrane a favorable binding conformation. From this data, it is believed that the length of spacers 1 and 2 play a significant role in defining hemolytic activity and thus these two distances (spacer lengths) are important for selectivity against bacterial cells versus mammalian cells. The preferred length of the spacers 1 and 2 should be between 5-15 angstroms to reduce hemolytic activity and the spacers may be as long as 50 angstroms.

In this invention, the two un-natural amino acids Tic (tetrahydroisoquinolinecarboxylic acid) and Oic (octahydroindolecarboxylic acid) are used to induce an amphipathic structure. It has been shown using NMR and molecular modeling methods that the dipeptide Tic-Oic when placed in positions $i+1$ and $i+2$ of a four amino acid sequence induced a β -turn. The inventors discovered that multiple Tic-Oic dipeptide units will induce back-to-back β -turns onto the polypeptide backbone. It was found that placement of multiple Tic-Oic units connected via two amino acid spacers induces a helical-like or cork-screw like conformation onto the peptide with defined properties of charge and hydrophobicity. Yet, and unexpectedly, the peptide backbone still exhibited sufficient conformational flexibility to allow interactions with membranes with different physicochemical properties to induce a "new" stable conformation onto the peptide.

The importance of the "Tic-Oic" β -turn inducing unit to the invention is illustrated by the following test and results. In order to systemically investigate the effects of varying the spacer and functional groups on selectivity and potency for the three different bacterial strains, compound FKAB-1G was selected based on its broad spectrum activity (activity against *Salmonella typhimurium*: (10 μ M), *Staphylococcus*

aureus ME/GM/TC resistant: (3 μ M) *Mycobacterium ranae*: (10 μ M), and *Bacillus subtilis* (1 μ M), coupled with relatively low hemolytic activity (14%) as the reference. The first hypothesis to be evaluated was the importance of the Tic-Oic dipeptide turn inducing unit to antibacterial and hemolytic activity. In the compound FKAB-1Gf the Tic residue was completely deleted from the sequence resulting in loss of activity against *Staphylococcus aureus* ME/GM/TC resistant and dramatic reduction in activity against *Salmonella typhimurium* from 10 to 100 μ M, and *Mycobacterium ranae*- from 10 to 100 μ M. Hemolytic activity was reduced to 6%. It is of interest to point out that FKAB-1Gf was still very active (3 μ M) against the Gram positive strain *Bacillus subtilis*. To determine whether dramatic reduction in activity was due to the reduction of the overall amino acid sequence length from 19 to 15. Compound FKAB-1Gf1 was prepared where all the Tic residues were replaced with Gly residues thus maintaining the overall amino acid sequence length of 19. This resulted in the loss activity against both *Salmonella typhimurium* and *Staphylococcus aureus* ME/GM/TC resistant bacteria while the activity against *Mycobacterium ranae* remained at 100 μ M. Again FKAB-1Gf1 was still relatively active against (30 μ M) *Bacillus subtilis*. A reduction in hemolytic activity (3%) was also observed for this analog. Two similar analogs were prepared completely deleting the Oic residue in FKAB-1Gg or in FKAB-1Gg1 replacing it with a Gly residue resulted in loss of activity against *Staphylococcus aureus* ME/GM/TC resistant and dramatic reduction in activity against *Salmonella typhimurium* (100 μ M) while still maintaining relatively good activity against *Bacillus subtilis*. A reduction of hemolytic activity of (6%) was also observed. However it is interesting to note that in both cases activity against *Mycobacterium ranae* was reduced only from 10 to 30 μ M. This observation provides critical insight into the conformational and hydrophobic requirements for selective binding to the membranes of mycobacterium vs. Gram positive and Gram negative bacteria. The final analog prepared in the series was compound FBAK-1Gh where the Tic residue was replaced by the non-conformationally restrained aromatic residue Phe, resulting in an analog exhibiting similar anti-bacterial activity to compound FKAB-1G; however a two fold increase in hemolytic activity (28%) was

observed. This indicates that in addition to playing a major role of inducing a turn conformation, the hydrophobicity of the Tic residue is also important for anti-bacterial activity and reducing hemolytic activity. To that end, the hydrophobic amino acid residues should exhibit hydrophobicity between -1.0 and -3.0 or higher on the octanol scale.

The following is a list of all un-natural amino residues that may be incorporated in one or more of the General Formulae. The list includes the three-letter designation and full name.

Dpr	2,3-diaminopropionic acid
Dab	2,4-diaminobutanoic acid
βAla	Beta Alanine
Gaba	Gama Aminobutyric acid
6-Ahx	6-Aminohexanoic acid
Nav	Norvaline
Nle	Norleucine
Apc4	4-Aminopiperidine-4-carboxylic acid
Apc3	3-Aminopiperidine-3-carboxylic acid
Tic	Tetrahydroisoquinoline-3-carboxylic acid
Oic	Octahydroindole-3-carboxylic acid
Thi	2-Thienylalanine
9-Aoa	9-Aminooctanoic acid
10-Ada	10-Aminodecanoic acid
12-Adda	12-Aminododecanoic acid
16-Apa	16-Aminopalmitic acid
Fpa	4-Fluorophenylalanine
Cph	4-Chlorophenylalanine

Nph 4-Nitrophenylalanine

Phg Phenylglycine

Regarding hemolytic activity, the data below shows a comparison of maximum tolerated dose study on six of the AMPs. From this data it appears that at possible therapeutic doses of 1, 5, and 25 mg/kg there is no correlation between toxicity and hemolytic activity (Table 5). Only at the higher dose of 125 mg/kg is there a clear toxicity problem. The toxicity will most likely be observed in the dose range of 50-125 mg/kg which at least 8 times higher dosage than the estimated therapeutic dose. As a point of reference, for a maximum tolerated dose study, Deslouches synthesized a series of AMPs composed of repeating Arg and Val residues to induce an idealized amphipathic α -helix secondary structure with substitution of Trp on the hydrophobic face of the helix to increase the over all hydrophobicity of the peptides. These peptides exhibited potent *in-vitro* antibacterial activity, however these analogs cause death of the treated mice at a dose of 16 mg/kg within 60 minutes.²²

Table 5. Maximum Tolerated Dose/Toxicity and Hemolytic activity

Peptide ID	1 mg/kg	5mg/kg	25mg/kg	125mg/kg	Hemolytic activity
FKAB-1Gc	minor weight loss/no observed toxicity	minor weight loss/no observed toxicity	minor weight loss/no observed toxicity	not tested	86%
FKAB-1Gd	minor weight loss/no observed toxicity	minor weight loss/no observed toxicity	minor weight loss/no observed toxicity	not tested	10%
FKAB-1Gb	no observed toxicity	no observed toxicity	no observed toxicity	not tested	43%
FKAB-1Ge	no observed toxicity	no observed toxicity	no observed toxicity	not tested	27%
FKAB-1G	not tested	no observed toxicity	no observed toxicity	minor weight loss in 4 or of 5 animals/ 1	14%

				death	
FKAB-1Gd1	not tested	no observed toxicity	minor weight loss/no observed toxicity	5 out of 5 animals died	25%

To evaluate the antibacterial activity of compounds within the general formula above, the following four bacterial strains were selected. 1) *Salmonella typhimurium* – because of its clinical relevance to evaluate activity against Gram-negative bacteria. 2) *Staphylococcus aureus* ME/GM/TC resistant-because of its clinical relevance to evaluate activity against drug resistant Gram positive bacteria. 3) *Mycobacterium ranae*- this is a commercially available screen for mycobacterium that hopefully will provide insight into activity against tuberculosis. 4) *Bacillus subtilis* was selected as a commercially available screen that will hopefully provide insight into activity against *Bacillus anthracis*. The results of obtained from these assays are given in Table 6.

Table 6: Minimum Inhibitory Concentration for Antimicrobial Activity and Hemolytic Activity (100 and 25 μ M) for all active analogs.

Peptide ID	<i>Salmonella typhimurium</i>	<i>Staphylococcus aureus</i> ME/GM/TC resistant	<i>Mycobacterium ranae</i>	<i>Bacillus subtilis</i>	% hemolysis 100/25 μ M	cmpnd #
WRFK-1	not active	10 μ M	not tested	not tested		1
WRFK-2	100 μ M	10 μ M	not active	1 μ M	100%	2
WRFK-3	not active	100 μ M	not tested	not tested	100%	3
WRFK-4	100 μ M	10 μ M	not tested	not tested	100%	4
WRFK-5	100 μ M	30 μ M	not active	3 μ M	100%	5
FKAB-1F	not active	10 μ M	30 μ M	1 μ M	63%	24
FKAB-1G	10 μ M	3 μ M	10 μ M	1 μ M	14%	25
FKAB-1H	10 μ M	3 μ M	10 μ M	1 μ M		26

FKAB-1L	30 μ M	10 μ M	10 μ M	3 μ M		27
FKAB-1Ga	3 μ M	10 μ M	10 μ M	1 μ M	33.4%/14.3%	28
FKAB-1Gb	3 μ M	30 μ M	3 μ M	1 μ M	43.6%/24.9%	29
FKAB-1Gc	10 μ M	3 μ M	30 μ M	1 μ M	86.8%/50%	30
FKAB-1Gd	10 μ M	100 μ M	10 μ M	1 μ M	10.8%/1.0%	31
FKAB-1Ge	10 μ M	10 μ M	3 μ M	1 μ M	26.7%/9.2%	32
FKAB-1Gf	100 μ M	not active	100 μ M	3 μ M	5.9%/3.2%	33
FKAB-1Gg	100 μ M	not active	30 μ M	10 μ M	6%/4.9%	34
FKAB-1Gg1	100 μ M	not active	30 μ M	10 μ M	5.70%/3.80%	35
FKAB-1Gf1	not active	not active	100 μ M	30 μ M	3.30%/3.3%	36
FKAB-1Gh	10 μ M	10 μ M	10 μ M	1 μ M	27.30%/8.9%	37
FKAB-1Gd1	10 μ M	10 μ M	1 μ M	1 μ M	24.4%/7.4%	38
FKAB-1Gd2	10 μ M	10 μ M	3 μ M	1 μ M	44.7%/26.6%	39
FKAB-1Gc1	10 μ M	3 μ M	3 μ M	1 μ M	41.3%/33.5%	40
FKAB-1Gi	10 μ M	3 μ M	3 μ M	1 μ M	24.9%/18.9%	41
FKAB-1Gd3	10 μ M	30 μ M	3 μ M	1 μ M	29.7%/10.5%	42
FKAB-1Gj	10 μ M	10 μ M	10 μ M	1 μ M	not tested	43
FKAB-1Go	30 μ M	10 μ M	3 μ M	0.3 μ M	not tested	44
FKAB-1Gp	3 μ M	3 μ M	10 μ M	0.3 μ M	not tested	45
FKAB-1Gi	30 μ M	3 μ M	10 μ M	1 μ m	not tested	46
FKAB-1Gs	3 μ M	10 μ m	100 μ M	1 μ M	not tested	47
FBAB-1Gw	3 μ M	30 μ M	100 μ M	0.3 μ M	not tested	48
FKAB-1G2	10 μ M	3 μ M	10 μ M	not tested	not tested	49

FKAB-1G3	10 μ M	10 μ M	10 μ M	not tested	not tested	50
FKAB-1Go2	30 μ M	30 μ M	10 μ M	not tested	not tested	51
FKAB-1G- β A	30 μ M	30 μ M	10 μ M	not tested	not tested	52
FKAB-1G-Gaba	30 μ M	10 μ M	3 μ M	not tested	not tested	53
FKAB-1G-Ahx	30 μ M	30 μ M	10 μ M	not tested	not tested	54
FKAB-1Gz	3 μ M	10 μ M	10 μ M	not tested	not tested	55
FKAB-1G-Thi	30 μ M	10 μ M	30 μ M	not tested	not tested	56
FKAB-1G-Trp	not active	30 μ M	100 μ M	not tested	not tested	57
FKAB-1Gx-R2	not tested	not tested	not tested	not tested	not tested	58
FKAB-1Gg2	100 μ M	100 μ M	10 μ M	not tested	not tested	59
FKAB-1Go1	not active	10 μ M	10 μ M	not tested	not tested	60
FKABB-1G1	100 μ M	100 μ M	30 μ M	not tested	not tested	61
FKAB-1Gv	10 μ M	100 μ M	30 μ M	not tested	not tested	62
FBAB-1Gq	100 μ M	30 μ M	3 μ M	not tested	not tested	63

As seen in Table 6 these compounds exhibit a broad spectrum of anti-bacterial and hemolytic activity. For the purposes of this study bioactivity is defined as an in vitro MIC of 100 μ M or less against a specific bacteria. The observed minimum inhibitory concentrations (MIC) for many of these analogs are as low or lower than those reported for other AMPs against *Staphylococcus aureus* strains^{33, 34 35}, Gram negative strains,³⁶ and mycobacterium strains³⁴.

As stated previously these compounds were engineered to mimic the electrostatic surface potential of (Ala^{8,13,18})magainin-2-amide. In Figure 3 the electrostatic surface potential map for one of the most active analogs FKAB-1G (activity against *Salmonella typhimurium* -10 μ M, *Staphylococcus aureus* ME/GM/TC resistant- 3 μ M and *Mycobacterium ranae*-10 μ M) is shown which clearly indicates that the compound is highly charged and amphipathic. By contrast, the electrostatic surface potential map for

the much less active analog FKAB-1Gf (activity against *Salmonella typhimurium* –100 μ M, *Staphylococcus aureus* ME/GM/TC resistant- IN ACTIVE, *Mycobacterium ranae*-100 μ M) shown in Figure 4, clearly indicates that the compound is highly charged, but the charge is not localized onto any one face of the molecule and therefore the molecule is not amphipathic. It is interesting to note that incorporation of the negatively charged penta-peptide (Glu-Leu-Met-Asn-Ser) found at the C-terminus of the magainins at either the C-terminus, or the N-terminus, or both, of these analogs not only dramatically reduced the hemolytic activity, but also eliminated the anti-bacterial activity. The effect of incorporation of this penta-peptide sequence at both the C and N terminus is shown by the electrostatic potential map of the completely inactive analog FKAB-4 is shown in Figure 5. This Figure suggests that the inactive analog is neither highly charged nor amphipathic.

In addition to exhibiting activity against a broad spectrum of bacteria *in-vitro* these compounds have also shown activity in the *in-vivo* mouse wound healing model. (Table 7) As seen in Figure 6, the three compounds evaluated exhibited activity very similar to the reference compound. In preparation of *in-vivo* anti-bacterial challenge studies six of the more active analogs were selected to determine the *in-vivo* maximum tolerated dose in a mouse model. The first four compounds were evaluated at doses of 1/5/25 mg/kg for 6 days- and none of these compounds exhibited any indications of major toxicity problems. (Table 5). Two other compounds were evaluated at 5/25/125 mg/kg and in both cases dosing at 125 mg/kg toxicity was observed. In the cases of compound FKAB-1G all animals lost weight and one animal died, while compound FKAB-1Gd1 exhibited much greater toxicity where 5 out of 5 animals died.

Table 7. Mouse wound healing model results ³²

Compound	Dose	Day 3	Day 5	Day 7	Day 9	Day 11	CT ₅₀
Vehicle	20 µl/mouse	19.7%	35.8%	49.6%	60.6%	66.4%	7.7 days
FKAB-1G	100 µg/mouse	36.3%	51.5%	63.3%	69.8%	77.5%	6.1 days
FKAB-1Gd	100 µg/mouse	39.7%	54.1%	64.9%	72.7%	79.0%	5.7 days
FKAB-1Gp	100 µg/mouse	38.8%	51.2%	67.2%	72.8%	81.1%	5.7 days
Control ^a	10 µg/mouse	41.1%	54.6%	70.6%	77.6%	84.3%	5.4 days

a: CGS-21680, denoting 2-p-[2-carboxyethyl]phenethyl-amino-5'-N-ethylcarboxamide-adenosine. This compound is a potent adenosine A_{2a} receptor agonists that promotes wound healing and was used as the reference standard in this study.

Spacers 1 and 2 are defined above. Additional spacers may be present, although as is self-evident from the general formulae, there can be only one spacer between an Oic residue and the cationic or hydrophobic residue. As noted previously, other spacers may exhibit greater conformational freedom allowing the peptide to adopt different conformations on interactions with red blood cells. It is noted that Gaba may be a spacer 1 and 2, but it cannot be a spacer 3.

Spacer 3 is defined as a cationic amino acid residue with a quaternary (protonated) terminal amine group, or similar positively charged nitrogen containing functionality at the end of the residues' side chain. (Generally speaking, there will not be a spacer 4.) Spacer 3 defines the distance from the side chain terminal amine group to the polypeptide backbone and the resulting conformational flexibility of the side chain charge. To determine whether or not this distance has any affect on antibacterial activity, analogs with three different side chain lengths were investigated: compound FKAB-1G containing Lys residues with four methylene groups in the side chain, compound FKAB-1Gp containing Orn residues with three methylene groups in the side chain, compound FKAB-1Gj where only the C-terminal Lys residues were replaced with Orn, and compound FKAB-1Gs containing Dpr residues with one methylene group in the side chain. (That is, in FKAB-1Gp all of the Lysine residues are replaced with Orn, while in compound FKAB-1Gj only the C-terminal Lysine residues are replaced with Orn residues the other two Lysines are not replaced. This compound is a mixed Lys Orn analog.)

The net result of this study was that these modifications had very little effect on activity in vitro against *Salmonella typhimurium* and *Staphylococcus aureus* ME/GM/TC resistant bacteria; however the activity against *Mycobacterium ranae* was dramatically reduced by 10 fold from 10 to 100 μ M. This result indicates that inclusion of Dpr residues will increase selectivity for Gram positive and Gram negative bacteria versus mycobacterium with a 33-fold selectivity for Gram negative and a 10-fold selectivity for Gram positive bacteria verse mycobacterium.

It is known that the Phe residues participate in hydrophobic interactions with the hydrophobic core of cell membrane. In an effort to determine whether changes in the electrostatic properties of Phe's aromatic ring will affect membrane binding the 4-Fluorophenylalanine (4FPhe or Fpa) analog FKAB-1Go was prepared. The net result was a small decrease in activity against *Salmonella typhimurium* and *Staphylococcus aureus* ME/GM/TC resistant bacteria and similar small increase in the activity against *Mycobacterium ranae*. This is a very interesting observation indicating that the hydrophobic interactions between these peptides and the membranes of mycobacterium are different from the hydrophobic interactions with Gram positive and Gram negative membranes. Therefore, it is preferred that for methods of treating mycobacterium in particular, the AMPs will include at least one Phe residue, but this is not absolutely required for the AMPs to be effective against mycobacterium. For example, the analog designated FKAB-1Ge (Ac-G-Tic-Oic-K-Tic-Oic-G-Tic-Oic-K-Tic-KKKK-CONH₂) does not contain a Phe residue nor does it contain spacer 1. However, it is quite active against the four bacterial strains, including mycobacterium.

As seen in Table 6 various other modifications produced only small variations in the observed in vitro anti-bacterial activity. Compound FKAB-1Gw containing β -Ala residues for spacers 1 and 2 and Dpr residues for spacer 3 exhibits the highest selectivity for *Salmonella typhimurium* with a 10-fold selectivity over *Staphylococcus aureus* ME/GM/TC resistant bacteria and a 33-fold selectivity over *Mycobacterium ranae*. Compound FKAB-1Gd3 with a 3-fold selectivity over *Salmonella typhimurium* and a 10-fold selectivity over *Staphylococcus aureus* ME/GM/TC resistant bacteria and compound FKAB-1Go with a 10-fold selectivity over *Salmonella typhimurium* and a 3-fold selectivity over *Staphylococcus aureus* ME/GM/TC resistant bacteria are the most selective analogs for *Mycobacterium ranae*. Compounds WRFK-2 and WRFK-4 exhibited 10-fold or greater selectivity *Staphylococcus aureus* ME/GM/TC resistant bacteria versus *Salmonella typhimurium* and *Mycobacterium ranae* – however, these compounds exhibit 100% hemolytic activity and are therefore not selective agents. This

does not mean that compounds WRFK-2 and WRFK-4 are not useful – they may be used as topical antibiotics since hemolytic activity is not as critical in topical treatments.

As shown by the data below in Table 8, the Tic-Oic dipeptide can be important for antibacterial potency and selectivity. The data supports that the Tic-Oic dipeptide unit is significant for effective broad spectrum in vitro antibacterial activity. Both the Gram Negative bacteria *Salmonella Typhimurium* and the Gram Positive *Staphylococcus Aureus* ME/GM/TC resistant are very sensitive to the Tic-Oic moiety. Complete removal of either the Tic or the Oic amino acid residue or the replacement of either the Tic or Oic amino acid residue with the amino acid Gly results in at least a 10 –fold loss in in vitro efficacy. Only replacement of the Tic amino acid with the amino acid Phe leads to significant in vitro activity against *Salmonella Typhimurium* and *Staphylococcus Aureus* ME/GM/TC. (Tic is a bicyclic analog of the amino acid Phe, both having similar hydrophobicity; however, Phe is more conformationally flexible than Tic.) Substitution of a second Tic residue for the Oic residue (the dipeptide Tic-Tic) as well as reversal of the Tic-Oic didpeptide to the Oic-Tic didpeptide results in a 10 –fold loss in in vitro activity against *Salmonella Typhimurium* and *Staphylococcus Aureus* ME/GM/TC.

It is significant that the modifications discussed immediately above have very little effect on the in vitro activity against the Gram Positive bacteria *Bacillus Subtilis*. The case with *Mycobacterium Ranae* is very different from the other three strains of bacteria, where a range of in vitro activity from 10 to 100 μ M is observed. It is therefore concluded that these modifications can be used to develop analogs with increased organism selectivity for *Mycobacterium* as compared to the Tic-Oic dipeptide containing analogs. The Tic-Tic and Oic-Tic analogs are shown to be particularly effective against mycobacterium. To that end, in another embodiment, this invention encompasses antimicrobial peptides selective against mycobacterium that include the Tic-Tic analog (such as for instance, compound 59, FKAB-1Gg2) and the Oic-Tic analog (such as for instance, compound 61, FKAB-1Gg1), or a combination of these analogs, as well as methods for selecting against mycobacterium using these peptides.

The four possible dipeptide units formed by linking the two un-natural amino acids, Tic and Oic are: Tic-Oic (the major unit used in the formulae of the invention), the reverse analog Oic-Tic, and two single amino acid analogs Tic-Tic and Oic-Oic. All four dipeptides induce a β -turn like structure onto the backbone of the peptide when incorporated into the sequence. Multiple dipeptides can induce a series of back to back β -turns or an α -helical like structure. The exact dihedral angles of these turns will vary depending on the dipeptide and its local chemical environment (i.e. in aqueous solution or bound to a lipid bilayer) the critical physicochemical parameter which is varied in each dipeptide is the distribution of the overall hydrophobicity over the surface of the dipeptide unit. The amino acid Tic is more hydrophobic than the amino acid Oic. The net hydrophobicity for the two dipeptides Tic-Oic and Oic-Tic will be similar, but the overall distribution of the hydrophobicity for these two dipeptides will be opposite, i.e. they will be mirror images of each other. The Tic-Tic dipeptide will have a net increase in hydrophobicity compared to Tic-Oic or Oic-Tic dipeptides, while Oic-Oic dipeptide will have a lower net hydrophobicity compared to the other three dipeptides. By careful use of these four dipeptide units the overall hydrophobicity presented to the bacterial cell membrane can be changed to complement the hydrophobic character of the membrane to result in analogs with greater selectivity and potency for a particular bacterial strain.

These antimicrobial peptides may be administered in the manner discussed elsewhere in this application, e.g., by topical, intravenous, infusion, and oral administration. For instance, the antimicrobial peptide may be administered by intravenous administration in a dosage regimen of 1-25 mg/kg per day.

In addition to the microorganisms described above, the peptides were screened for anti-bacterial activity in the following four select agent assays: *Bacillus anthracis*, *Yersinia pestis* (plague), *Francisella tularensis* and *Brucella melitensis*. The test substance/vehicle was added to test wells containing the selected microorganisms (1×10^4 to 5×10^5 CFU/mL) in the appropriate culture medium under controlled conditions. Final incubation concentration was determined by reference to standard optical density

curve. After 1 -4 days, growth of the culture was examined and scored positive (+) for inhibition of growth or turbidity or negative (-) for no effect upon growth or turbidity. Samples were evaluated at concentrations of 100, 30, 10, 3, 1, 0.3 and 0.1 μ M in 1% DMSO to determine minimal inhibitory concentration (MIC). See Table 9 for results.

Table 8: Tic-Oic Dipeptide and Antibacterial Activity

Peptide ID	<i>Salmonella Typhimurium</i>	<i>Staphylococcus Aureus</i> ME/GMTC resistant	<i>Mycobacterium Ranae</i>	<i>Bacillus Subtilis</i>	% hemolysis 100/25 μ M	Peptide ID	Analog
25	10 μ M / 24 μ g/mL	3 μ M / 7.2 μ g/mL	10 μ M / 24 μ g/mL	1 μ M / 2.4 μ g/mL	14%	FKAB-1G	Tic-Oic
33	100 μ M / 180 μ g/mL	not active	100 μ M / 180 μ g/mL	3 μ M / 5.4 μ g/mL	5.9% / 3.2%	FKAB-1Gf	No Tic
34	100 μ M / 200 μ g/mL	not active	30 μ M / 60 μ g/mL	10 μ M / 20 μ g/mL	6% / 4.9%	FKAB-1Gg	No Oic
35	100 μ M / 220 μ g/mL	not active	30 μ M / 66 μ g/mL	10 μ M / 22 μ g/mL	5.70% / 3.80%	FKAB-1Gg1	Gly for Oic
36	not active	not active	100 μ M / 200 μ g/mL	30 μ M / 60 μ g/mL	3.30% / 3.3%	FKAB-1Gg1	Gly for Tic
37	10 μ M / 24 μ g/mL	10 μ M / 24 μ g/mL	10 μ M / 24 μ g/mL	3 μ M / 7.2 μ g/mL	27.30% / 8.9%	FKAB-1Gh	Phe for Tic
59	100 μ M	100 μ M	10 μ M	not tested	not tested	FKAB-1Gg2	Tic-Tic
61	100 μ M	100 μ M	30 μ M	not tested	not tested	FKAB-1G1	Oic-Tic

Peptide #	<i>F. tularensis</i> SCHU-S4 μg/mL	<i>Bacillus anthracis</i> Ames μg/mL	<i>B. melitensis</i> 16M μg/mL	Plaque CO92 μg/mL
56	250	1.95	>500	15.6
55	125	0.98	>500	15.6
54	250	1.95	>500	15.6
52	250	1.95	>500	31.25
24	>500	0.98	>500	>500
34	250	0.98	>500	31.25
60	500	1.95	>500	7.8
59	250	3.91	>500	31.25
45	500	1.95	>500	31.25
53	>500	0.98	>500	31.25
57	>500	0.98	>500	>500
44	250	0.98	>500	31.25
38	500	1.95	>500	125

Table 9: Minimum Inhibitory Concentration for Antimicrobial Activity against Select Agents

It is concluded that the peptides, especially compounds 24, 34, 38, 44, 45, 52-57, 59 and 60 are effective against *Bacillus anthracis* and *Yersinia pestis* (plague). These compounds exhibit very good to excellent in vitro MIC activity against two biological warfare agents. Both of these agents are difficult to treat using existing antibiotic drugs. The compounds of this invention has a mechanism of action that is novel and offers protection against genetically modified strains of these two biological warfare agents. Another embodiment of the invention is use and methods of use of certain peptides in the treatment and prevention of infection by *Bacillus anthracis* and *Yersinia pestis* (plague). In addition, compounds 34, 44, 52, 54, 56, and particularly compound 55 may be useful compounds as biactive against *Francisella tularensis*. These antimicrobial peptides may be administered in the manner discussed elsewhere in this application, e.g., by topical, intravenous, infusion, and oral administration. For instance, the antimicrobial peptide may be administered by intravenous administration in a dosage regimen of 1-25 mg/kg per day.

The following provides details regarding the development and testing of the novel AMPs. This information is not intended to limit the invention to the specific AMPs described, but supports the novelty of the AMPs that fall within the General Formulae.

NMR All ^1H NMR data was collected using a Bruker Avance-600 spectrometer using a ^1H , ^{13}C , ^{15}N z-gradient cyroprobe. The samples of each peptide were prepared in—A) 100 mM SDS micelles and B) 100 mM DPC micelles in 600 μL of 90% $\text{H}_2\text{O}/10\%\text{D}_2\text{O}$ buffered with 150 mM sodium acetate to a pH of 4.2. 1D- ^1H spectra were collected using the WATERGATE (WATER suppression by GrAdient Tailored Excitation) water suppression pulse sequence developed by Sklenar and co-workers³⁷ Data was collected at a temperature of 300 K. The spectral width was 9090.9 Hz acquired with 128K data points in F_2 . 16 scans were collected for each spectrum. Spectra was processed using XWINNMR (Bruker) on a Hewlett Packard workstation.

In-vitro assays: All peptides were screened for anti-bacterial activity in the following four in-vitro assays: 1) *Salmonella typhimurium* (ATCC 13311) Gram negative,^{38, 39} 2) *Staphylococcus aureus*- Methicillin/Gentamicin/Tetracycline Resistant (ATCC 33592) Gram positive,⁴⁰ 3) *Bacillus subtilis* (ATCC 43223) Gram positive,^{38, 39} 4) *Mycobacterium ranae* (ATCC 110)^{38, 39} by MDS Pharma Services using the following protocol. The test substance/vehicle was added to test wells containing the selected microorganisms (1×10^{-4} to 5×10^{-5} CFU/mL) in the appropriate culture medium under controlled conditions. Final incubation concentration was determined by reference to standard optical density curve. After 1 - 4 days, growth of the culture was examined and scored positive (+) for inhibition or growth or turbidity or negative (-) for no effect upon growth or turbidity. Samples were evaluated at concentrations of 100, 30, 10, 3, 1, 0.3 and 0.1 μ M in 1% DMSO to determine minimal inhibitory concentration (MIC).

In-vivo assays: Selected compounds were evaluated in an *in-vivo* mouse skin wound healing model by MDS Pharma Services using the following protocol. Groups of CD-1 derived male mice (n=5) weighting 24 ± 2 g were used. Under hexobarbitol (90 mg/kg, IP) anesthesia, the shoulder and back region of each animal was shaved. A sharp punch (ID 12 mm) was applied to remove the skin including *panniculus carnosus* and adherent tissues. Test substances at 100 μ g/mouse were each administered topically immediately following cutaneous injury, once daily for 10 consecutive days. The reference standard for this study 2-p-[2-carboxyethyl]phenethyl-amino-5'-N-ethylcarboxamide-adenosine. The wound area, traced onto clear plastic sheets, was measured by use of an Image-ProPlus (Media Cybernetics, Version 4.5.0.29) on days 1, 3, 5, 7, 9, and 11. The percent closure of the wound (%) was calculated, and wound half-closure time (CT₅₀) was analyzed by linear regression using Graph-Prism (Graph Software USA). One-way ANOVA followed by Dunnett's test was applied for comparison between the treated and its corresponding vehicle groups at each measurement time point. Differences are considered statistically significant at $P < 0.05$.⁴¹

Maximum Tolerated Dose: Six compounds were evaluated in an in vivo mouse model to determine the maximum tolerated dose for each compound by BIOCON, Inc. using the following protocol. For each compound 3 dose concentrations (1/5/25 mg/kg or 5/25/125 mg/kg) were administered IP, 1-2 times per day as split doses. Day 0 weigh the animals, day 1-6 dose daily and observe animals, day 7 weigh, euthanasia followed by necrotize to examine abdominal cavity.

Hemolytic Studies: Took 5 mL of whole blood, spun down at 2500 rpm for 5 minutes, decanted supernatant, washed with PBS (20 mL each time, pH 7.4, isotonic) six times or until the supernatant became clear, and re-suspended in 125 mL of PBS to obtain a 4 % count. Used 500 μ L each for the experiments.

Peptide Synthesis: All of the above mentioned peptides were synthesized at 60 μ M scale using an Advanced Chemtech ACT 396 model, multiple peptide synthesizer. Standard Fmoc chemistry was followed for the synthesis.⁴²⁻⁴⁴ Rink Amide MBHA resins [4(2',4'-Dimethoxyphenyl-Fmoc-aminomethyl)-phenoxyacetamido-L-norleucyl-p-methyl benzhydrylamine resin] (purchased from NovaBioChem) was used as the solid phase and DMF (Dimethyl Formamide) was used as the primary transfer and wash solvent. A 20% piperidine solution in DMF was used for deprotection. A solution of HBTU (O-Benzotriazole-N,N,N',N'-tetramethyluroniumphosphate) in conjunction with HOBT (1-Hydroxy Benzotriazole) in DMF was used as the coupling agent and 5 % acetic anhydride in DMF was used for capping. DIPEA (Diisopropylethyl amine, 2 M in N-Methylmorpholine) was used as the tertiary amine in the coupling step. All amino acids were dissolved in NMM (N-Methylmorpholine) Upon completion of the synthesis, the resin was thoroughly washed with Methanol (5 times), dried overnight under high vacuum (0.05 torr) and cleaved using a cocktail containing TFA (88%), Water (5%), Phenol (5%) and Triisopropylsilane (2%) for 3 hours. This mixture of resin and cleave cocktail was filtered followed by addition to cold (-20 °C) stabilizer free dry diethyl ether (10mL). The precipitated peptide was centrifuged and the supernatant was removed. This pellet of peptide was repeatedly washed with dry diethyl ether (20 mL x 2) and dried

overnight under high vacuum. The crude peptide thus obtained was dissolved in 0.1 % TFA (Trifluoroacetic acid) and a 1% aliquot is saved for HPLC and MS analysis. [Hicks, 2007, #19]

Peptide Purification and analyses: All HPLC analyses were carried out using an Agilent 1100 series Analytical instrument (equipped with autosampler and Diode Array Detector) and C18 Narrow Bore Reverse Phase Column (250 x 2.1 mm, 5 μ M particle size, 100 μ L per minute flow rate). The mobile phase A consisted of Water (97.5 %, containing 0.5 mL TFA) and 2-Propanol (2.5 %) while B consisted of MeCN (88.88 %), Water (8.88 %, containing 0.4 mL of TFA) and 2-Propanol (2.4 %). All analyses were carried out under gradient conditions (1-90 % B over 60 minutes). All crude peptides were purified to 97 % or more for analytical and other experimental purposes. All preparative purifications were carried out using an Agilent 1100 Series Preparative Instrument and C18 Reverse Phase Preparative Column (250 x 22 mm, 10 μ M particle size, 10 mL per minute flow rate) using same mobile phases. All purified peptides were analyzed again by HPLC and Mass-Spec. Mass Spectral analyses were carried out using a Finnigan LTQ ESI-MS instrument running Xcalibur 1.4SR-1 or a Kratos PC Axima CFR Plus instrument (MALDI) running Kompact V2.4.1. ESI-MS showed multiply charged ions and the accurate mass was calculated. MALDI analyses were performed in reflectron mode and hence in most cases (M+H)⁺ ion corresponding to Monoisotopic mass was observed (Table 10. AMP Mass Data). In the case of compounds showing only (M+Na)⁺ or (M+K)⁺ peaks, the mass was confirmed by running the same experiment in negative ion mode. [Hicks, 2007, #19]

Table 10. AMP Analytical Mass Spec Data

Name	Sequence	Average MW Calcd. (M ⁺)	Monoisotope MW Calcd. (M ⁺)	Observed MW (M+H) ⁺
WRFK-1	NH ₂ -GKGL-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-CONH ₂	3540.43	3538	3539.80
WRFK-2	NH ₂ -GKGL-Tic-Oic-GR-Tic-Oic-GR-Tic-Oic-GR-Tic-Oic-GR-Tic-Oic-GR-CONH ₂	3624.47	3622.02	3623.60
WRFK-3	NH ₂ -GKGL-Tic-Oic-GL-Tic-Oic-GL-Tic-Oic-GL-Tic-Oic-GL-Tic-Oic-GL-CONH ₂	3442.36	3440.01	3441.90
WRFK-4	NH ₂ -GKGL-Tic-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-CONH ₂	3472.39	3470.03	3471.80
WRFK-5	NH ₂ -GKGL-Tic-Oic-FK-Tic-Oic-FK-Tic-Oic-FK-Tic-Oic-FK-Tic-Oic-FK-CONH ₂	4043.18	4040.34	4042.00
FKAB-1F	NH ₂ -KL-Tic-Oic-K-Tic-Oic-K-Tic-Oic-K-Tic-Oic-K-Tic-Oic-K-Tic-Oic-K-CONH ₂	3084.01	3081.83	3082.70
FKAB-1G	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-CONH ₂	2441.07	2439.40	2440.60
FKAB-1H	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-CONH-CH ₂ -CH ₂ -NH ₂	2484.14	2482.44	2483.30
FKAB-1L	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-CONH-CH ₂ -CH ₂ -NH ₂	2498.17	2496.46	2497.50
FKAB-1Ga	NH ₂ -GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-CONH ₂	2414.05	2412.40	2437.5 (M+Na)
FKAB-1Gb	NH ₂ -KL-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-CONH ₂	2451.16	2449.49	2450.20
FKAB-1Gc	Ac-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-Oic-K-Tic-Oic-K-Tic-Oic-K-CONH ₂	2212.86	2211.32	2212.90
FKAB-1Gd	Ac-Gaba-F-Tic-Oic-Gaba-K-Tic-Oic-Gaba-F-Tic-Oic-Gaba-K-Tic-Oic-Gaba-K-CONH ₂	2553.29	2551.53	2552.60
FKAB-1Ge	Ac-G-Tic-Oic-K-Tic-Oic-G-Tic-Oic-G-Tic-Oic-K-Tic-Oic-K-Tic-Oic-K-CONH ₂	2032.61	2031.22	2032.60
FKAB-1Gf	Ac-GF-Oic-GK-Tic-Oic-GF-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-Tic-Oic-GK-CONH ₂	1804.32	1803.13	1804.40

FKAB-1Gg	Ac-GF-Tic-GK-Tic-GF-Tic-GK-Tic-KKKK-CONH ₂	1987.44	1986.10	1987.50
FKAB-1Gg1	Ac-GF-Tic-G-GK-Tic-G-GF-Tic-G-GK-Tic-KKKK-CONH ₂	2158.60	2157.17	2158.20
FKAB-1Gp	Ac-GF-G-Oic-GK-G-Oic-GF-G-Oic-GK-G-KKKK-CONH ₂	2032.53	2031.21	2032.60
FKAB-1Gh	Ac-GF-F-Oic-GK-F-Oic-GF-F-Oic-GK-F-KKKK-CONH ₂	2393.03	2391.40	2392.20
FKAB-1Gd1	Ac-βAla-F-Tic-Oic-βAla-K-Tic-Oic-βAla-F-Tic-Oic-βAla-K-Tic-KKKK-CONH ₂	2497.18	2495.46	2496.50
FKAB-1Gd2	Ac-Ahx-F-Tic-Oic-Ahx-K-Tic-Oic-Ahx-F-Tic-Oic-Ahx-K-Tic-KKKK-CONH ₂	2665.61	2663.65	2664.30
FKAB-1Gc1	Ac-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-KKKK-CONH ₂	2469.21	2467.51	2468.50
FKAB-1Gi	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH ₂	2569.25	2567.50	2568.70
FKAB-1Gd3	Ac-Gaba-F-Tic-Oic-Gaba-K-Tic-Oic-Gaba-F-Tic-Oic-Gaba-K-Tic-KKKK-CONH ₂	2681.47	2679.62	2680.60
FKAB-1Gj	Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Orm-Orm-Orm-CONH ₂	2384.97	2383.34	2384.30
FKAB-1Go	Ac-G-Fpa-Tic-Oic-GK-Tic-Oic-G-Fpa-Tic-Oic-GK-Tic-KKKK-CONH ₂	2477.05	2475.38	2476.30
FKAB-1Gp	Ac-GF-Tic-Oic-G-Orm-Tic-Oic-GF-Tic-Oic-G-Orm-Tic-Orm-Orm-CONH ₂	2356.91	2355.31	2356.30
FKAB-1Gi	Biotin-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH ₂	2625.33	2623.47	2624.30
FKAB-1Gs	Ac-GF-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-Dpr-Dpr-Dpr-CONH ₂	2188.59	2187.12	2188.90
FKAB-1Gw	Ac-βAla-Fpa-Tic-Oic-βAla-Dpr-Tic-Oic-βAla-Fpa-Tic-Oic-βAla-Dpr-Tic-Dpr-Dpr-CONH ₂	2280.68	2279.16	2280.90
FKAB-1G2	Ac-G(dF)-Tic-Oic-GK-Tic-Oic-G(dF)-Tic-Oic-GK-Tic-KKKK-CONH ₂	2441.07	2439.40	2440.40
FKAB-1G3	Ac-GF-Tic-Oic-G(dK)-Tic-Oic-GF-Tic-Oic-G(dK)-Tic-KKKK-CONH ₂	2441.07	2439.40	2440.40
FKAB-1G2	Ac-G-Nph-Tic-Oic-GK-Tic-Oic-G-Nph-Tic-Oic-GK-Tic-KKKK-CONH ₂	2531.07	2529.37	2530.80

Metabolic Stability

Liver microsomal incubations were performed to obtain preliminary estimates metabolic stability. Selected compounds were incubated in pooled liver microsomes from human, monkey, dog, rat, and mouse, and the test article percent remaining was measured by LC-MS/MS. Test results showed that the compounds exhibited acceptable to excellent metabolic stability in human liver microsomes as well as liver microsomes of four other species. This demonstrates that these compounds should exhibit satisfactory metabolic stability in humans for the treatment of systemic bacterial infections.

As can be seen in Table 11 below, for the results (high, moderate, low and very low) for all metabolic stability testing in the five species at T=60 minutes in the table below, all 20 analogs exhibit very good to excellent first pass metabolic stability in several species—specifically and most importantly in humans. However, as seen from the data below The inventors have the ability to modify the metabolic stability of these compounds which in turn will allow us to control the therapeutic half-life of these compounds. This control will allow for the adjustment of the dosing scheme to be used, for example once a day, once every other day, etc. Please see tables below for additional details.

Table 11: Metabolic Stability

compound #	metabolic stability T=60 min human	metabolic stability T=60 min monkey	metabolic stability T=60 min dog	metabolic stability T=60 min rat	metabolic stability T=60 min mouse
25	high	high	Moderate	high	very low
29	high	high	Moderate	high	moderate
30	high	high	Low	high	very low
31	high	high	High	high	very low
38	high	high	Moderate	high	moderate
32	high	high	Moderate	high	very low
41	high	high	High	high	very low
43	high	high	Moderate	high	very low
46	high	high	High	high	high
24	high	very low	very low	high	very low
52	very low	high	High	low	high
53	very low	high	High	high	moderate
54	very low	high	High	high	high
56	high	very low	High	high	very low
57	high	very low	High	very low	high
55	very low	high	very low	high	low
26	very low	very low	No data	No data	moderate
37	high	high	Moderate	very low	high

The test articles were incubated in pooled liver microsomes from human, monkey, dog, rat, and mouse. Test article percent remaining was measured by LC-MS/MS. The samples consisted of the test articles at 1 μ M, pooled microsomes at 0.5 mg/mL final protein concentration, and an NADPH regenerating system in a final volume of 200 μ L. Water was used as the test article solvent. The assay was standardized for both phosphate buffer (75 mM, pH 7.4) and the NADPH regenerating system (MgCl_2 , 3.3 mM; G6P, 3.3 mM; G6PD, 0.4 U/mL; NADP^+ , 1.3 mM). Positive controls included warfarin, propranolol, and testosterone, incubated as a cocktail.

Results for all metabolic stability testing are also summarized in Table 12.

Table 12. Summary of Metabolic Stability Testing

	Human Liver				Monkey Liver		
Warfarin	100%	97%	97%		113%	109%	81%
Propranolol	97%	86%	72%		34%	9%	0.50%
Testosterone	77%	53%	29%		34%	11%	1%
25	152%	145%	140%		55%	73%	91%
29	98%	97%	106%		86%	87%	97%
30	139%	134%	128%		17%	24%	75%
31	106%	94%	114%		16%	25%	76%
38	94%	99%	97%		90%	87%	89%
32	114%	116%	120%		56%	73%	125%
41	86%	95%	113%		72%	75%	99%
44	103%	119%	210%		57%	65%	94%
46	144%	136%	120%		80%	77%	77%
24	99%	224%	153%		28%	29%	9%

52	133%	122%	-1%		130%	125%	181%
53	118%	146%	21%		117%	120%	153%
54	112%	123%	-13%		134%	131%	183%
56	234%	220%	253%		206%	194%	-40%
57	112%	137%	108%		0%	0%	0%
55	1383%	800%	-550%		194%	119%	200%
26	34%	151%	51%		0%	0%	0%
37	92%	105%	147%		137%	146%	141%

Dog Liver

T=15 T=30 T=60

Warfarin	109%	104%	94%
Propranolol	76%	51%	24%
Testosterone	85%	62%	33%
25	54%	50%	63%
29	100%	99%	81%
30	22%	14%	46%
31	35%	34%	55%
38	84%	78%	71%
32	43%	43%	54%
41	68%	63%	79%
44	63%	54%	59%
46	96%	84%	80%
24	54%	27%	8%
52	-6%	66%	105%
53	67%	80%	86%

54	83%	79%	84%
56	66%	61%	140%
57	58%	116%	169%
55	-84%	-4%	3%
26	NC	NC	NC
37	-27%	103%	60%

	Rat liver				Mouse liver		
	T=15	T=30	T=60		T=15	T=30	T=60
Warfarin	93%	97%	84%		86%	111%	110%
Propranolol	0.10%	0.10%	0.10%		9%	9%	4%
Testosterone	0%	0%	0%		3%	0%	0%
25	71%	79%	90%		80%	10%	12%
29	84%	84%	91%		87%	73%	70%
30	73%	80%	107%		86%	10%	7%
31	67%	78%	83%		90%	7%	9%
38	82%	79%	92%		90%	64%	53%
32	69%	73%	95%		85%	20%	11%
41	76%	86%	87%		77%	26%	15%
44	74%	57%	75%		81%	26%	22%
46	73%	83%	105%		96%	87%	78%
24	113%	120%	202%		124%	45%	22%
52	118%	122%	44%		11%	174%	156%
53	113%	72%	104%		88%	71%	66%
54	120%	106%	121%		97%	98%	113%
56	107%	61%	199%		41%	67%	-21%

57	131%	84%	0%		54%	81%	106%
55	21%	7%	80%		74%	29%	42%
26	NC	NC	NC		0%	62%	73%
37	313%	284%	0%		36%	71%	112%

Values are shown as % remaining at time T (in minutes)

In Vivo Antimicrobial Efficacy

Five compounds were selected for *in vivo* challenge against a gram-positive and a gram-negative infection. Each test involved 60 subjects – 10 for control and 10 for treatment with five selected compounds each. *Streptococcus pneumoniae* serotype 6B was selected for the gram-positive test, and *Salmonella typhimurium* strain LT2 was selected for the gram-negative test.

All five compounds used in the streptococcus challenge demonstrated significant protection (> 90% survival). Prolonged survival (up to 70%) was noted for recipients of two compounds tested against salmonella infection. See Figures 15 and 16, where Series 1 = control group; Series 2 = compound 25; Series 3 = compound 38; Series 4 = compound 44; Series 5 = compound 46; Series 6 = compound 24.

All treated subjects were given an initial treatment injection of 5 mg/kg in the afternoon of the first day of the challenge, followed by a morning and afternoon injection of 2.5 mg/kg for the remainder of the challenge period.

Sixty ICR mice received 0.1 ml (5×10^6) of the challenge bacterium *Streptococcus pneumoniae* serotype 6B, via intraperitoneal injection. All untreated controls died from bacterial infection by day 21. All drug treatments demonstrated significant protection (> 90% survival).

Sixty Balb/c mice received 0.1 ml (2.5×10^6) of the challenge bacterium *Salmonella typhimurium* strain LT2 via intraperitoneal injection. All Untreated controls died from bacterial infection by day 4. Accelerated morbidity was observed (decreased survival compared to control group) among recipients of FKAB-1Gd1 and FKAB-1Gp. Prolonged survival (up to 70%) was noted among recipients of compounds FKAB-1Go and FKAB-1F. This data demonstrates that these compounds exhibit good to very good in vivo efficacy against a Gram positive and and a Gram negative systemic bacterial infections. This data coupled with the maximum tolerated dose studies indicates that these compounds are effective against Gram positive and and a Gram negative systemic bacterial infections at concentrations much lower than their lethal dose. Early estimates of their therapeutic index is greater than 20 : 1.

Quantitative Structure Activity Relationship (QSAR) and analysis

The inventors have successfully built highly predictive 3D-QSAR models for the above-described novel unnatural amino acids containing antimicrobial peptides. As noted above, these AMPs exhibit extremely potent activity against *Salmonella typhimurium*, *Staphylococcus aureus*, *Mycobacterium ranae*, and *Bacillus subtilis*. For the purposes of this invention, bioactivity is defined as in vitro MIC of 100 μ M or less against a specific bacteria. Employing the recently reported bioactive conformer mining methodology, the inventors have computed highly predictive models for *Staphylococcus aureus* (SA) and *Mycobacterium ranae* (MR) with non-validated r^2 of 0.987 and 0.998 respectively. The SA and MR models performed well on internal validation tests, with leave-one-out correlation q^2_{LOO} of 0.839 and 0.997 and leave-10%-out correlation q^2_{L100} of 0.875 and 0.537 respectively.

The QSAR models concur with the reported mechanism of action involving electrostatic physicochemical properties such as polar surface areas and high positive charge. The models also show the importance of shape by demonstrating that physicochemical properties such as density and solvent accessible surface areas correlate with bioactivity. The SA QSAR model indicates that polarity and electrostatics are more

significant in bioactivity manifestation for the anionic membrane bearing gram-positive *Staphylococcus aureus*; whereas, the MR QSAR model indicates that hydrophobicity and shape are more important in exhibiting bioactivity for the mycolate rich membrane bearing *Mycobacterium ranae*. Thus, the inventors' findings concur with the reported findings that amphipathicity, high positive charge and specific shape are required for AMP to exhibit bioactivity. Further, effective and efficient use of Tcl-based Cerius2 scripts is demonstrated in development of predictive QSAR models for highly flexible AMPs.

The predictive 3D-QSAR defining the activity of these analogs against *Staphylococcus aureus*; and *Mycobacterium ranae* clearly supports the importance of various physicochemical properties in defining organism potency and selectivity. The sixteen physiochemical properties common to the SA and MR QSAR models are shown in Table 13. See Table 2 for definitions of these properties.

Table-13. Common & Different PC properties between the two models

Commonality of Physico-chemical properties	<i>Mycobacterium ranae</i> QSAR_DSP	<i>Staphylococcus aureus</i> QSAR_DSP
Common to both of the models	AlogP	AlogP
	Density	Density
	Dipole-mag	Dipole-mag
	Fcharge	Fcharge
	Hbond acceptor	Hbond acceptor
	Hbond donor	Hbond donor
	Jurs-FNSA-3	Jurs-FNSA-3
	Jurs-FPSA-1	Jurs-FPSA-1
	Jurs-PNSA-1	Jurs-PNSA-1
	Jurs-PNSA-2	Jurs-PNSA-2
	Jurs-PPSA-1	Jurs-PPSA-1

	Jurs-RPCG	Jurs-RPCG
	Jurs-RASA	Jurs-RASA
	Jurs-RPSA	Jurs-RPSA
	RadOfGyration	RadOfGyration
	Rotlbonds	Rotlbonds
Specific to single model	Apol	
	Conformer Energy	
	Jurs-PPSA-2	
	Jurs-RNCG	
	Jurs-TPSA	
		Jurs-FPSA-3
		Jurs-RPCS
		Jurs-DPSA-2
		Jurs-DPSA-3
		Jurs-SASA
		Jurs-TASA

While the five physicochemical properties specific to the MR QSAR model are Apol (partition coefficient computed on atom types), Conformer Energy, Jurs-PPSA-2 (The partial positive solvent-accessible surface area times the total positive charge), Jurs-RNCG (relative negative charge computed by dividing the charge of the most negative atom by the total negative charge), and Jurs-TPSA (the total polar surface area, which is the sum of the solvent-accessible surface areas of atom with absolute partial charges greater than or equal 0.2). The commonality of physicochemical properties show the minimal requirement for activity against SA and

MR. The physicochemical properties such as Dipole-mag, (Dipole moment magnitude: The dipole moment descriptor is a 3D electronic descriptor that indicates the strength and orientation behavior of a molecule in an electrostatic field. Both the magnitude and the components (X, Y, Z) of the dipole moment are calculated. It is estimated by utilizing partial atomic charges and atomic coordinates. Partial atomic charges are computed using the charge setup option in the QSAR control panel offering CHARMM charging rules, Gasteiger, CNDO2, and Del Re methods. The descriptor uses Debye units. Dipole properties have been correlated to longrange ligand-receptor recognition and subsequent binding. Fcharge (Sum of all formal charges in the molecule), Jurs-FNSA-3 ([the sum of the products of solvent accessible surface area and partial charge for all positively charged atoms]/[total molecular solvent-accessible surface area], Jurs-RPSA (relative polar surface area), Jurs-FPSA-1 [partial positive solvent accessible area]/[total molecular solvent-accessible surface area]), Jurs-PNSA-1 (sum of the solvent-accessible surface area of all partially negatively charged atoms), Jurs-PNSA-2 (partial negative solvent-accessible surface area times the total negative charge), Jurs-PPSA-1 (partial positive solvent accessible area), and Jurs-RPCG (relative positive charge computed by dividing the charge of the most positive atom by the total positive charge) indicate the importance of electrostatic potential for the AMPs bioactivity. This property is controlled by the inter-relationship of Spacers 1 and 2 as well as by Spacer 3 (the distance of the side chain terminal quaternary amine and the peptide backbone.) While the physicochemical properties such as Density (A 3D spatial descriptor that is defined as the ratio of molecular weight to molecular volume. It has the units of g ml⁻¹. The density reflects the types of atoms and how tightly they are packed in a molecule. Density can be related to transport and melt behavior) H-bond acceptor, (Total number of hydrogen-bond acceptors in the molecule), Jurs-RASA {[total hydrophobic surface area, which is computed as the sum of the solvent-accessible surface area of atoms with absolute partial charge less than 0.2.]/(total molecular solvent accessible surface)}], H-bond donor (Total number of hydrogen-bond donors

in the molecule) , RadOfGyration, Radius of gyration - The radius of gyration is calculated using the following equation:

$$Rog = \sqrt{\left(\sum \frac{(x_i^2 + y_i^2 + z_i^2)}{N} \right)}$$

where N is the number of atoms and x, y, z are the atomic coordinates relative to the center of mass and Rotlbonds {Counts the number of bonds in the current molecule having rotations that are considered to be meaningful for molecular mechanics. All terminal H atoms are ignored (for example, methyl groups are not considered rotatable)} indicate the significance of the AMP molecular shape (appropriate conformation) for bioactivity. These properties are controlled by the Tic-Oic dipeptide and the inter-relationship between the cationic and hydrophobic residues as defined by Spacers 1 and 2. The importance of amphiphilicity is alluded to by the physicochemical properties such as Jurs-RASA {[total hydrophobic surface area, which is computed as the sum of the solvent-accessible surface area of atoms with absolute partial charge less than 0.2.)/(total molecular solvent accessible surface)}, Jurs-RPSA (relative polar surface area), and AlogP (Log of the partition coefficient calculated using the method described by Ghose & Crippen ^{45, 46}. In this atom-based approach, each atom of the molecule is assigned to a particular class, with additive contributions to the total value of logP) These properties are controlled by Tic-Oic dipeptide and the inter-relationship between Spacers 1 and 2 and the resulting conformational flexibility.

By way of background, it is noted that Quantitative Structure Activity Relationship (QSAR) is among the most widely used techniques in rational drug design. Following the pioneering work of Hansch, *et al* ⁴⁷ in 2D-QSAR, several sophisticated techniques like Comparative Molecular Field Analysis (CoMFA) ⁴⁸, Molecular Shape Analysis (MSA) ⁴⁹, Comparative Molecular Similarity Index Analysis (CoMSIA) ⁵⁰, Condensed Phase Optimized Molecular Potentials for Atomistic Simulation Studies (COMPASS) ⁵¹, and Hypothetical Active Site Lattice (HASL) ⁵² have been developed for

three dimensional QSAR (3D-QSAR). Several novel two-dimensional QSAR (2D-QSAR) descriptors to quantify the topology and information-content of molecules have been recently reported. Among them are the Weiner ⁵³, Zagreb ⁵⁴, and Hosoya indices ⁵⁵, the Kier and Hall molecular connectivity indices ⁵⁶, the Kier and Hall subgraphs count indices ⁵⁶, the Kier's shape indices ⁵⁷, molecular flexibility indices ⁵⁸, and the Balaban indices ⁵⁹. The 2D molecular graph based graph-theoretic descriptors recently reported are the information-content-info of atomic composition descriptors ⁶⁰, information index based on adjacency matrix (A-matrix), distance matrix (D-matrix), Edge matrix (E-matrix), and edge-distance matrix (ED-matrix) ⁵⁴, the sum of atomic polarizability ⁶¹, and the multi-graph information content indices ⁵⁴. Several novel 3D descriptors to capture the conformational electronic and spatial information have also been reported. Among the recently reported 3D descriptors are shadow indices ⁶² and Jurs indices ⁶³. All of the 2D and 3D descriptors have been widely used in QSAR models. For example, in anti-tubercular agents ⁶⁴, sulfamates have been used to distinguish sweet, sweet-bitter, and bitter tasting molecules ⁶⁵, and octopaminergic agonists to inhibit sex-pheromones production in insects ⁶⁶.

The selection of bioactive conformer is among the most important challenges in QSAR analysis ⁶⁷. Numerous sophisticated techniques have been reported to address this challenge, such as by Hopfinger *et al* ⁶⁸ using conformational averaging or conformational ensembles; by Hasagewa *et al* ⁶⁹ employing several conformers in multi-way data arrays; by Vedani *et al* ⁷⁰ using multi-conformational ligand representation; by Appell *et al* ⁷¹ invoking tensor decomposition; by Hasagewa *et al* ⁶⁷ employing three-way-PLS analysis; by Xiao *et al* ⁷² propounding the Targacept Active Conformational Search algorithm; and by Sulea *et al* ⁷³ employing the multi-conformational minimal topologic difference (MTD-ADJ) using adjusted biological activities.

1. Material and Methods

The inventors have previously shown that employing several conformers, of highly flexible cyclic pentapeptides, in a CoMFA based QSAR study coupled with

several sequential partial least square analyses mimicking the multi-way-Partial Least Square analysis, they could develop highly predictive QSAR models ⁷⁴. The inventors extended the method with a semi-automated heuristic using the Cerius2 software package ⁷⁵ to develop highly predictive 3D-QSAR models for insect repellents.⁷⁶

Cerius2 (C2) version 4.9 ⁷⁵ and InsightII version 2001 running on a Silicon Graphics Octane workstation under IRIX 6.5 operating system were used for all of the modeling work presented here. Gasteiger ⁷⁷ charges, ClassII force field ⁷⁸ was used for all of the computations using C2, and Consistent Valence force field (CVFF) was used for all computations using InsightII. Unless otherwise noted, default C2 and InsightII settings were used.

All peptides were screened for antibacterial activity in the following four *in-vitro* assays: 1) *Salmonella typhimurium* (ATCC 13311) Gram negative, 2) *Staphylococcus aureus* Methicillin/Gentamicin/Tetracycline resistant (ATCC 33592) Gram positive, 3) *Bacillus subtilis* (ATCC 43223) Gram positive, 4) *Mycobacterium ranae* (ATCC 110) by MDS Pharma services using the following protocol. The test substance/vehicle was added to test wells containing the selected microorganisms (1×10^{-4} to 5×10^{-5} CFU/ml) in the appropriate culture medium under controlled conditions. Final inoculum concentration was determined by reference to standard optical density curve. After 1-4 days, growth of the culture was examined and stored positive (+) for inhibition or growth or turbidity or negative (-) for no effect upon growth or turbidity. Samples were evaluated at concentration of 100, 30, 10, 3, 1, 0.3 and 0.1 M in 1% DMSO to determine Minimal Inhibitory Concentration (MIC).

The Table 14 summarizes the AMPs and their biological activity sequences data used in this QSAR study.

Table 14 Biological activity data

Peptide ID	<i>Salmonella typhimurium</i>			<i>Staphylococcus aureus</i> ME/GM/TC resistant)			<i>Mycobacterium ranae</i>			<i>Bacillus Subtilis</i>		
	μM	p(MIC)	μM	p(MIC)	μM	p(MIC)	μM	p(MIC)	μM	p(MIC)	μM	p(MIC)
FKAB-1	1000000	0.00	not tested		not tested		not tested		not tested		not tested	
FKAB-1F	1000000	0.00	10.00	5.00	30.00	4.52	30.00	4.52	1.00	6.00	1.00	6.00
FKAB-1G	10	5.00	3.00	5.52	10.00	5.52	10.00	5.00	1.00	6.00	1.00	6.00
FKAB-1Ga	3	5.52	10.00	5.00	10.00	5.00	10.00	5.00	1.00	6.00	1.00	6.00
FKAB-1Gb	3	5.52	30.00	4.52	3.00	5.52	3.00	5.52	1.00	6.00	1.00	6.00
FKAB-1Gc	10	5.00	3.00	5.52	30.00	4.52	30.00	4.52	1.00	6.00	1.00	6.00
FKAB-1Gcl	10	5.00	3.00	5.52	3.00	5.52	3.00	5.52	1.00	6.00	1.00	6.00
FKAB-1Gd	10	5.00	100.00	4.00	10.00	5.00	10.00	5.00	1.00	6.00	1.00	6.00
FKAB-1Gdl	10	5.00	10.00	5.00	1.00	6.00	1.00	6.00	1.00	6.00	1.00	6.00
FKAB-1Gd2	10	5.00	10.00	5.00	3.00	5.52	3.00	5.52	1.00	6.00	1.00	6.00
FKAB-1Gd3	10	5.00	30.00	4.52	3.00	5.52	3.00	5.52	1.00	6.00	1.00	6.00
FKAB-1Ge	10	5.00	10.00	5.00	3.00	5.52	3.00	5.52	1.00	6.00	1.00	6.00
FKAB-1Gf	100	4.00	1000000	0.00	100.00	4.00	100.00	4.00	3.00	5.52	3.00	5.52
FKAB-1Gfl	1000000	0.00	1000000	0.00	100.00	4.00	100.00	4.00	30.00	4.52	30.00	4.52
FKAB-1Gg	100	4.00	1000000	0.00	30.00	4.52	30.00	4.52	10.00	5.00	10.00	5.00
FKAB-1Ggl	100	4.00	1000000	0.00	30.00	4.52	30.00	4.52	10.00	5.00	10.00	5.00
FKAB-1Gh	10	5.00	10.00	5.00	10.00	5.00	10.00	5.00	1.00	6.00	1.00	6.00
FKAB-1Gi	10	5.00	3.00	5.52	3.00	5.52	3.00	5.52	1.00	6.00	1.00	6.00
FKAB-1Gj	10	5.00	10.00	5.00	10.00	5.00	10.00	5.00	1.00	6.00	1.00	6.00
FKAB-1Go	30	4.52	10.00	5.00	3.00	5.52	3.00	5.52	0.30	6.52	0.30	6.52
FKAB-1Gp	3	5.52	3.00	5.52	10.00	5.00	10.00	5.00	0.30	6.52	0.30	6.52

FKAB-1H	10	5.00	3.00	5.52	10.00	5.00	1.00	6.00
FKAB-1L	30	4.52	10.00	5.00	10.00	5.00	3.00	5.52
FKAB-4	1000000	0.00	1000000	0.00	1000000	0.00	1000000	0.00
WRFK-1	1000000	0.00	10.00	5.00	not tested		not tested	
WRFK-2	100	4.00	10.00	5.00	1000000	0.00	1.00	6.00
WRFK-3	1000000	0.00	100.00	4.00	not tested		not tested	
WRFK-4	100	4.00	10.00	5.00	not tested		not tested	
WRFK-5	100	4.00	30.00	4.52	1000000	0.00	3.00	5.52

Molecular Structure building, Conformational Search, & Cluster Analyses

Each peptide molecule was built using the Biopolymer module, and minimized using steepest descent algorithm ⁷⁹ and a brief molecular dynamics run. Conformational searches were performed using the Boltzmann Jump method ⁸⁰ as implemented in C2. The parameters used were as follows: Torsion window was fixed to 120, temperature was set to 5000K, and number of perturbations was set to 50. The torsion bond is defined as a single bond connecting different groups, which on rotation would give rise to potential local minimum conformer. Tcl-based Cerius2 scripts were developed to automate the repetitive conformational searches.

The inventors performed cluster analysis based on the RMS (root mean squares) differences of the torsion angles between the conformers. The steps in the algorithm are well known,⁷⁵ and a general description is as follows: All of the conformers are sorted by energy. The lowest energy conformer is assigned to the first cluster and it becomes the cluster nuclei. Next, all the conformers that have RMS difference below the specified threshold value are placed in the first cluster. The lowest energy conformer of the remaining unclustered conformers is placed in the second cluster as its cluster nuclei. Again, all the conformers that have rms difference below the specified threshold value are placed in the second cluster. The above two steps are repeated until all the conformers are placed into clusters.

Preliminary cluster analysis was performed to generate 10-20, 20-30, 30-40 and 40-50 conformers per cluster. The cluster nuclei of each set were examined for 3D-spatial representation. The cluster nuclei for the 10-20 set showed poor 3D-spatial representation, while cluster nuclei in the 40-50 conformer sets showed crowding in some region. The cluster nuclei of the 20-30 and 30-40 conformers set showed the best 3D sampling for most of the AMPs. Consequently, the inventors selected the best set of conformational clusters, showing the best 3D-spatial representation, between 20-40 for the QSAR analysis.

Descriptor Computation and QSAR Model Building

A total of 50 descriptors were computed for all of the conformers using the default setting in C2. The correlation matrix computed for the all the descriptor values of all the conformers of all peptides. Partial Least Square analysis (PLS) was used to compute the QSAR models with the descriptor column auto scaled and means removed. The number of components to explore was set to six, unless otherwise noted.

Quasi-multi-way PLS analyses

The partial least squares (PLS) method ⁷⁵ is used when there are far more independent variables (descriptors) than observations and when there is co-linearity in the independent variables. The inventors used the following PLS parameters: 6 components to explore, the column means removed, and the column data auto-scaled. The internal 'regression-only' cross-validation was used during the model building process. The definitions of the statistical terms used in this paper are well known.

The multi-way PLS method, developed by Bro *et al* ⁸¹, was applied to develop the 3D-QSAR models of insecticidal neonicotinoid compounds ⁸². Each dimension of the multi-way data corresponds to the compounds in training set, CoMFA field variables, conformations, and alignments. The conformers and alignments that gave the best correlation to observed bioactivities were determined from the multi-way PLS solution. The inventors have mimicked the multi-way-PLS analyses by performing several sequential two-way PLS analyses on the data. The inventors used a Tcl based Cerius2 script ⁷⁴ to automate the repetitive task of several PLS analyses.

Computation of Electrostatic Potential Surfaces

Electrostatic potential surfaces for the selected AMP conformers were computed as follows. The electrostatic potential were computed employing a grid with origin at its grid points, resolution of 65 points per axis and solute extending to 80 Å. The solute was defined with Gasteiger charges, VDW radii, dielectric constant of 2.0 and point charge

distribution. The solvent dielectric constant was set to 80, solvent radii set to 1.4 Å, ionic strength set to 0.145 and the ionic radii was set to 2.0 Å. The molecular surfaces computed were Connolly surfaces with solid display style, using atom radii scale of 1.0, atom radii increment of 0.0 and probe radius of 1.4 Å. The surfaces were colored with Delphi spectrum using electrostatic potential grid as coloring method.

Conformational Search and Cluster Analysis

All peptides were subjected to Boltzmann Jump method of conformational search and a total of 2000 conformers were obtained. The global minimum conformer for each compound was obtained by exhaustive minimization of the least energy conformer. Table 15 summarizes the conformational search and cluster analysis data. The inventors used Tcl-based Cerius2 scripts⁷⁴ to automate the repetitive task of conformational searches and cluster analyses.

Table 15. Conformational Search & Cluster Analysis Data

Compd #	Global min Energy Kcals/mol	# Torsion bonds	Highest Energy value of conformer	# Clusters Obtained	Energy Difference between Global minimum and Highest Energy conformer
FKAB-1	-160.00	98	44.16	57	-204.16
FKAB-1F	-127.22	79	-123.53	38	-3.69
FKAB-1G	87.03	78	96.28	29	-9.25
FKAB-1Ga	111.83	76	136.26	22	-24.43
FKAB-1Gb	93.33	80	100.15	27	-6.82
FKAB-1Gc	38.93	66	53.26	30	-14.33
FKAB-1Gc1	89.01	80	89.87	24	-0.86
FKAB-1Gd	-141.01	86	-126.59	31	-14.42
FKAB-1Gd1	-152.67	82	-150.70	31	-1.97
FKAB-1Gd2	-164.14	94	-155.86	29	-8.28
FKAB-1Gd3	-157.57	93	-154.66	25	-2.91
FKAB-1Ge	99.21	62	100.00	26	-0.79
FKAB-1Gf	28.86	70	30.99	29	-2.13

FKAB-1Gf1	41.49	82	42.95	26	-1.46
FKAB-1Gg	50.76	72	51.27	24	-0.51
FKAB-1Ggl	92.11	81	93.71	29	-1.60
FKAB-1Gh	-32.71	90	-20.09	26	-12.62
FKAB-1Gi	78.81	85	89.36	26	-10.55
FKAB-1Gj	133.86	74	140.37	25	-6.51
FKAB-1Go	74.62	78	77.57	24	-2.95
FKAB-1Gp	84.66	72	92.62	25	-7.96
FKAB-1H	136.76	81	138.66	24	-1.90
FKAB-1L	137.15	82	143.25	24	-6.10
FKAB-4	-154.45	106	-149.25	39	-5.20
WRFK-1	-49.38	103	-48.64	32	-0.74
WRFK-2	-845.89	103	-842.75	25	-3.14
WRFK-3	-51.90	99	-46.09	25	-5.81
WRFK-4	-37.00	103	-35.75	24	-1.25
WRFK-5	-161.13	119	-140.11	24	-21.02

This methodology mines the 3D-encompassing conformations cluster nuclei to identify the conformer that most closely correlate with bioactivity. Further, the use of the gradual, stepwise refinement gives steady enrichment of bioactive conformers in each successive model.

3D-QSAR Model Development

Descriptor Computation

A total of 50 different 2D and 3D descriptors were calculated for all the compounds. The thermodynamic descriptors included are n-octanol/water partition coefficient (LogP), the desolvation free energy for water (Fh2o), the desolvation free energy for n-octanol (Foct), the partition coefficient computed on atom types reported by

Ghosh *et al*^{45, 46} (AlogP and AlogP98), the molar refractivity (MR) computed based on refractive index, molecular weight, compound density, and the molar refractivity (MolRef) computed based on the atom-types with additive contributions reported by Ghosh *et al*^{45, 46}. The thirty Jurs descriptors based on partial charges mapped on surface area were reported by Stanton *et al*⁶³ and are described in Table 2.

The four quantum mechanical descriptors included are HOMO_MOPAC, LUMO_MOPAC, DIPOLE_MOPAC, and HF_MOPAC. These are the HOMO, LUMO, dipole moment and heat of formation calculated by semi-empirical methods, which are generally known to provide more accurate values. The 3D-spatial descriptors are Density, and PMI-mag. The descriptor Density is defined as the ratio of molecular weight to molecular volume. The descriptor PMI-Mag is the magnitude of the principal moments of inertia about the principal axes of the conformers as described by Hill⁸³. The descriptor Hf is a thermodynamic descriptor that gives the enthalpy of formation of the conformer as described by Dewar *et al*⁸⁴. The conformational descriptor 'Energy' gives the energy of the conformer.

Descriptor Selection

The selection of descriptors is an important first step in QSAR study. A good correlation between the selected variables and the bioactivity will entail better bioactivity predictions⁸⁵. The inventors adapted the descriptor selection strategy, reported earlier by Yao *et al*⁸⁶. First, all descriptors that had very low correlation with bioactivity ($-|r| < \sim 0.01$) were discarded. Next, the highly collinear descriptors ($-|\text{cross correlation coefficient}| > \sim 0.9$) were identified. Those descriptors with more physical significance to offer mechanistic insight in the QSAR information were retained. For example, given a choice between Jurs-DPSA-2, Molecular weight, and HOMO, the Jurs-DPSA-2 was retained because it provides information about the difference between the positive and negative charged solvent accessible surface areas.

The cross correlation matrix was computed for the two models *Staphylococcus aureus* (SA), and *Mycobacterium ranae* (MR). The descriptors that showed very poor correlation with bioactivity ($r < 0.01$) were removed. Table 16 shows the discarded descriptors and their correlation coefficients with bioactivity for the four models.

The cross correlation matrix showed that, all but 31 descriptors exhibited very high cross correlation ($-|r| > \sim 0.9$). Table 17 summarizes the descriptor types, names and their cross-correlation coefficient values. These descriptors were removed to leave four sets of 23 different final descriptors which are shown in Table 18 for the two models.

Table 16 List of Descriptors with correlation of less than 0.01 with Bioactivity (BA)

<i>Staphylococcus aureus</i>			0.039		
Descriptor	0.036	0.036	<i>Mycobacterium ranae</i>		
Foct	-0.035	0.035			
Fh2o	0.029	0.029	Descriptor	Correlation with BioActivity	Abs(BA)
Jurs-RNCS	-0.028	0.028	Conformer Rank	-0.079	0.079
Jurs-WPSA-2	-0.024	0.024	Jurs-RPCS	-0.074	0.074
Jurs-TPSA	0.009	0.009	Fh2o	-0.061	0.061
Area	0.008	0.008	Jurs-RNCS	-0.049	0.049
MR	-0.008	0.008	MR	0.049	0.049
Jurs-RNCG	-0.005	0.005			

Table 17. Highly correlated ($|r| > \sim 0.9$) Descriptors and their Cross Correlation coefficients (Part 1)

Jurs-SASA		Apol		Jurs-PPSA-2	
Jurs-SASA	1.000	Apol	1.000	Jurs-PPSA-2	1.000
Jurs-WPSA-1	0.992	Vm	0.998	Jurs-DPSA-2	0.995
Jurs-PPSA-1	0.981	Area	0.994	Jurs-WPSA-2	0.982
Jurs-TASA	0.971	Chiral centers	0.946	Jurs-WPSA-3	0.971
Jurs-WNSA-1	0.939	Jurs-PPSA-1		Jurs-FPSA-2	0.942
PMI-mag	0.924			Jurs-DPSA-3	0.935
Area	0.910			Jurs-WNSA-2	-0.924
				Jurs-PPSA-3	0.911
Jurs-PNSA-1		Jurs-PNSA-2			
Jurs-PNSA-1	1.000	Jurs-PPSA-1	1.000	Jurs-PNSA-2	1.000
Jurs-WPSA-1	0.989	Jurs-WPSA-1	0.989	Jurs-WNSA-2	0.980
Jurs-SASA	0.981	Jurs-SASA	0.981	Jurs-WNSA-3	0.978
Jurs-TASA	0.951	Jurs-TASA	0.951	Jurs-PNSA-3	0.962
Jurs-DPSA-1	0.950	Jurs-DPSA-1	0.950	Jurs-FNSA-2	0.958
Jurs-FNSA-3		Jurs-DPSA-1			
Jurs-FNSA-2	0.905	Jurs-DPSA-1			
Jurs-PNSA-3	0.903				
		Jurs-DPSA-1	1.000	Jurs-DPSA-2	-0.934

Jurs-WPSA-1		Jurs-PPSA-1		Jurs-DPSA-3	
Jurs-WPSA-1	1.000	Jurs-PPSA-1	0.950	Jurs-DPSA-3	-0.905
Jurs-SASA	0.992	Jurs-WPSA-1	0.904		
Jurs-PPSA-1	0.989				
Jurs-TASA	0.964				
PMI-mag	0.919				
Jurs-WNSA-1	0.911				
Jurs-DPSA-1	0.904				
Area	0.899				

Jurs-TASA		Jurs-DPSA-2	
Jurs-TASA	1.000	Jurs-DPSA-2	1.000
Jurs-SASA	0.971	Jurs-PPSA-2	0.995
Jurs-WPSA-1	0.964	Jurs-WPSA-2	0.974
Jurs-PPSA-1	0.951	Jurs-WNSA-2	-0.954
Jurs-WNSA-1	0.910	Jurs-WPSA-3	0.950
Area	0.903	Jurs-DPSA-3	0.946
		Jurs-FPSA-2	0.942
		Jurs-PNSA-2	-0.934
		Jurs-WNSA-3	-0.919

Area		Jurs-PPSA-3	
Area	1.000	Jurs-PPSA-3	1.000
Vm	0.999	Jurs-WPSA-3	0.946
Apol	0.994	Jurs-DPSA-3	0.933
Chiral centers	0.946	Jurs-FPSA-2	0.921

Jurs-WNSA-1	
Jurs-WNSA-1	1.000
Jurs-PNSA-1	0.967
Jurs-SASA	0.939
PMI-mag	0.933

Table 17. Highly correlated ($|r| > \sim 0.9$) Descriptors and their Cross Correlation coefficients (Part 2)

Jurs-WPSA-1	0.911
Jurs-TASA	0.910

Jurs-WPSA-2

Jurs-WPSA-2	1.000
Jurs-PPSA-2	0.982
Jurs-DPSA-2	0.974
Jurs-WPSA-3	0.970
Jurs-WNSA-2	-0.927

Jurs-WNSA-2

Jurs-WNSA-2	1.000
Jurs-WNSA-3	0.981
Jurs-PNSA-2	0.980
Jurs-DPSA-2	-0.954
Jurs-WPSA-2	-0.927
Jurs-PPSA-2	-0.924
Jurs-PNSA-3	0.914

Jurs-SASA	0.910	Jurs-PPSA-2	0.911
Jurs-TASA	0.903		

Jurs-PNSA-3

Vm		Jurs-PNSA-3	1.000
Vm	1.000	Jurs-WNSA-3	0.962
Area	0.999	Jurs-PNSA-2	0.962
Apol	0.998	Jurs-FNSA-2	0.959
Chiral centers	0.952	Jurs-WNSA-2	0.914
PMI-mag		Jurs-FNSA-3	0.903
		Jurs-DPSA-3	-0.902

Jurs-DPSA-3

PMI-mag	1.000	Jurs-DPSA-3	1.000
RadOfGyrat	0.937	Jurs-FPSA-2	0.950
Jurs-WNSA-1	0.933	Jurs-DPSA-2	0.946
Jurs-SASA	0.924	Jurs-PPSA-2	0.935
Jurs-WPSA-1	0.919	Jurs-PPSA-3	0.933
Chiral centers		Jurs-WNSA-3	-0.912
Chiral centers	1.000	Jurs-WPSA-3	0.909
Vm	0.952		

Jurs-WPSA-3			Jurs-PNSA-2		
Jurs-WPSA-3	1.000		Apol	0.946	-0.905
Jurs-PPSA-2	0.971		Area	0.946	-0.902
Jurs-WPSA-2	0.970				
Jurs-DPSA-2	0.950				
Jurs-PPSA-3	0.946				
Jurs-DPSA-3	0.909				

Fh2o			Jurs-FPSA-1		
Fh2o	1.000		Jurs-FNSA-1	-1.000	
Foct	0.980		Jurs-FPSA-1	1.000	
MR	-0.918				

Table 17. Highly correlated ($|r| > \sim 0.9$) Descriptors and their Cross Correlation coefficients (Part 3)

Jurs-WNSA-3			Jurs-FNSA-2			Jurs-FNSA-1		
Jurs-WNSA-3	1.000		Jurs-FNSA-2	1.000		Jurs-FPSA-1	-1.000	
Jurs-WNSA-2	0.981		Jurs-PNSA-3	0.959		Jurs-FNSA-1	1.000	
Jurs-PNSA-2	0.978		Jurs-PNSA-2	0.958				
Jurs-PNSA-3	0.962		Jurs-FNSA-3	0.905				
Jurs-DPSA-2	-0.919		Jurs-WNSA-3	0.900				
Jurs-DPSA-3	-0.912		AlogP			Jurs-FPSA-2	1.000	
Jurs-FNSA-2	0.900					Jurs-DPSA-3	0.950	
Foct			AlogP			Jurs-DPSA-2	0.942	
						Jurs-PPSA-2	0.942	
						Jurs-PPSA-3	0.921	

Foct	1.000	AlogP98		RadOfGyration	
Fh2o	0.980	AlogP98	1.000	RadOfGyration	1.000
MR	-0.930	AlogP	0.927	PMI-mag	0.937

MR

MR	1.000
Foct	-0.930
Fh2o	-0.918

Table 18. Selected Descriptors for the two QSAR Models

<i>Staphylococcus aureus</i>	<i>Mycobacterium ranae</i>
Fcharge	Conformer Energy
Dipole-mag	Fcharge
Jurs-SASA	Apol
Jurs-PPSA-1	Dipole-mag
Jurs-PNSA-1	Jurs-PPSA-1
Jurs-PNSA-2	Jurs-PNSA-1
Jurs-DPSA-2	Jurs-PPSA-2
Jurs-DPSA-3	Jurs-PNSA-2
Jurs-FPSA-1	Jurs-FPSA-1
Jurs-FPSA-3	Jurs-FNSA-3
Jurs-FNSA-3	Jurs-RPCG
Jurs-RPCG	Jurs-RNCG
Jurs-RPCS	Jurs-TPSA
Jurs-TASA	Jurs-RPSA
Jurs-RPSA	Jurs-RASA
Jurs-RASA	Density
Density	Hbond acceptor
Hbond acceptor	Hbond donor
Hbond donor	Rotlbonds
Rotlbonds	AlogP
AlogP	Foct
LogP	LogP
RadOfGyration	RadOfGyration

Quasi-multi-way PLS analyses

Bhonsle *et al*⁷⁴ has reported the use of automated quasi-multi-way PLS analyses for CoMFA based 3D-QSAR of cyclic pentapeptides CXCR4 inhibitors. They have

mimicked the multi-way-PLS analyses by employing several automated two-way-PLS analyses using SYBYL⁸⁷ software. The PLS analysis procedure in C2 provides for a quick cross-validation of QSAR models. In this cross-validation procedure, only the “regression” part of the model development is cross-validated. This “regression-only” cross-validation was computed for all generation QSAR models. The non-validated r^2 and the sum of squares of predicted residual (PRESS) was used to guide the successive generations of model development. Bhonsle *et al*⁷⁴ have demonstrated a successful application of this approach for computation of highly predictive QSAR models for insect repellents.

Staphylococcus aureus (SA) and *Mycobacterium ranae* (MR) QSAR model development

The first generation SA and MR QSAR model were obtained by performing PLS analysis on 820 and 682 conformers of the twenty-nine and twenty-five AMPs respectively. The computed QSAR model showed non-validated r^2 of 0.695 and 0.873, and sum of squares of predicted residuals (PRESS) of 1560.52 and 273.96 respectively. The second (IInd) generation SA and MR models of 549 and 454 conformers were obtained as follows. The predicted residual values of several conformers of the same compound in the first generation model showed almost identical values. A closer examination of the descriptor values of all such conformers showed that the descriptor values were also almost identical. Thus, all such ‘duplicate’ conformers were removed. The computed SA and MR QSAR models showed non-validated r^2 of 0.698 and 0.878, and PRESS value of 1081.29 and 185.54 respectively.

For all of the following QSAR models, the inventors eliminated the worst residual value conformer in a stepwise and gradual fashion. The inventors used the non-validated r^2 and PRESS as measures to guide the model improvement.

The IIIrd generation SA and MR models of 290 and 250 conformers were obtained by selecting 10 least residual values conformers and it showed non-validated r^2 of 0.677 and 0.874, and PRESS value of 502.99 and 100.23. While, the IVth generation

SA and MR models of 145 and 125 conformers were constructed with five least residual value conformers from IIIrd generation SA and MR models respectively. These models displayed non-validated r^2 of 0.682 and 0.88, and PRESS value of 269.75 and 54.98, respectively for the SA and MR models. The Vth generation SA and MR models of 58 and 50 conformers were obtained with two least residual value conformers, and it exhibited non-validated r^2 of 0.687 and 0.879, and PRESS value of 185.75 and 30.12 respectively. The VIth generation SA and MR models of 58 and 50 conformers were obtained by employing 22 components instead of 6 to furnish more complex, but better models, with non-validated r^2 of 0.972 and 0.995, and PRESS value of 84.84 and 17.96 respectively. The VIIth generation model for *Staphylococcus aureus* was constructed by eliminating the worst residual value conformers of all AMPs with $p(\text{MIC})$ with $p(\text{MIC})$ {viz. $-\log(\text{MIC})$ } less than 4.52. For the remaining 12 AMPs, namely FKAB-1Go, FKAB-1I, FKAB-1F, WRFK-1, WRFK-2, WRFK-4, FKAB-1G, FKAB-1Gc1, FKAB-1Gc, FKAB-1Gi, FKAB-1Gp, and FKAB-1H, two conformers each were retained in the model. This QSAR model with 41 conformers had non-validated r^2 of 0.972, and PRESS value of 84.84. Whereas, the VIIth generation model for *Mycobacterium ranae* was constructed by removing the worst residual value conformers of all AMPs with $p(\text{MIC})$ less than 4.52. For the remaining 12 AMPs, namely FKAB-1Gj, FKAB-1I, FKAB-1Gd2, FKAB-1Gd3, FKAB-1Ge, FKAB-1Go, FKAB-1Gb, FKAB-1Gc1, FKAB-1Gd1, FKAB-1Gi, FKAB-1Gp, and FKAB-1H, two conformers each were retained in the model. This QSAR model with 37 conformers had non-validated r^2 of 0.993, and PRESS value of 29.19.

At this juncture, there were 24 conformers from which the best set of 12 conformers could be chosen in 4096 (2^{12}) ways for both of the SA and MR QSAR models. The inventors used a Tcl-based Cerius2 script ⁷⁴ to compute these 4096 eighth (VIIIth) generation models. The inventors found the best SA and MR models with leave-one-out (regression-only) cross-validated r^2 of 0.421 and 0.598 respectively. These VIIIth generation SA and MR QSAR model showed non-validated r^2 of 0.988 and 0.997, leave-

one-out cross-validated r^2 of 0.839 and 0.997, and PRESS value of 22.92 and 29.19 respectively.

The statistical data of all the eight-generation models, for the *Salmonella typhimurium*, *Staphylococcus aureus*, and *Mycobacterium ranae*, obtained during the QSAR model development phases, is presented in Table 19.

Table 19. All Generation QSAR Models Statistical data

	QSAR Model Generation Number	Number of Conformers in Model	Non-validated r ²	Leave-One-Out Cross-validated (regression only) q ²	PRESS
<i>Staphylococcus aureus</i>	1	820	0.695	0.687	1560.53
	2	549	0.698	0.686	1081.29
	3	290	0.677	0.647	502.99
	4	145	0.682	0.621	269.75
	5	58	0.687	0.347	185.75
	6	58	0.965	0.672	93.23
	7	41	0.972	0.467	84.84
	8	29	0.988	0.839	22.92
<i>Mycobacterium ranea</i>	1	682	0.873	0.869	273.96
	2	454	0.878	0.872	185.54
	3	250	0.874	0.862	100.23
	4	125	0.88	0.849	54.98

	5	50	0.879	0.793	30.12
	6	50	0.995	0.876	17.96
	7	37	0.993	0.5	40.62
	8	25	0.997	0.598	29.19

The QSAR Models/Equations

QSAR equation analysis

The *Staphylococcus aureus* QSAR model is described by the following equation:

$$\begin{aligned} \text{SA Predicted Activity} = & -1.49592 * \text{"Fcharge"} + 0.0098147 * \text{"Dipole-mag"} + 0.013993 \\ & * \text{"Jurs-SASA"} + 0.00233 * \text{"Jurs-PPSA-1"} + 0.187647 * \text{"Jurs-PNSA-1"} + 0.0021686 * \\ & \text{"Jurs-PNSA-2"} + 0.00036919 * \text{"Jurs-DPSA-2"} + 0.0015025 * \text{"Jurs-DPSA-3"} + 438.251 \\ & * \text{"Jurs-FPSA-1"} + 267.258 * \text{"Jurs-FPSA-3"} + 120.432 * \text{"Jurs-FNSA-3"} - 715.316 * \\ & \text{"Jurs-RPCG"} - 12.8649 * \text{"Jurs-RPCS"} - 0.065752 * \text{"Jurs-TASA"} - 125.513 * \text{"Jurs-} \\ & \text{RPSA"} + 125.513 * \text{"Jurs-RASA"} - 183.99 * \text{"Density"} + 1.03397 * \text{"Hbond acceptor"} + \\ & 0.039473 * \text{"Hbond donor"} - 0.306856 * \text{"Rotlbonds"} + 0.114808 * \text{"AlogP"} - 0.10004 * \\ & \text{"RadOfGyration"} - 225.589 \end{aligned}$$

The *Staphylococcus aureus* QSAR model with the selected conformers, predicted bioactivities, and residual values is presented in Table 20.

Table 20. Predictive *Staphylococcus aureus* QSAR Model selected conformers, predicted Bioactivities, and residual prediction errors.

AMP ID	Conformer #	Actual Bioactivity	Model # A Predicted Bioactivity	Residual of Predicted Bioactivity
FKAB-1F	19	5.000	5.072	-0.07
FKAB-1G	6	5.520	5.105	0.42
FKAB-1Ga	8	5.000	4.906	0.09
FKAB-1Gb	10	4.520	4.335	0.19
FKAB-1Gc	11	5.520	5.824	-0.30
FKAB-1Gc1	10	5.520	5.851	-0.33
FKAB-1Gd	14	4.000	4.407	-0.41
FKAB-1Gd1	4	5.000	4.522	0.48
FKAB-1Gd2	16	5.000	5.380	-0.38

FKAB-1Gd3	6	4.520	3.597	0.92
FKAB-1Ge	13	5.000	5.006	-0.01
FKAB-1Gf	9	0.000	-0.016	0.02
FKAB-1Gf1	11	0.000	0.175	-0.18
FKAB-1Gg	2	0.000	-0.033	0.03
FKAB-1Gg1	1	0.000	0.480	-0.48
FKAB-1Gh	1	5.000	4.675	0.32
FKAB-1Gi	8	5.520	6.350	-0.83
FKAB-1Gj	17	5.000	4.294	0.71
FKAB-1Go	1	5.000	4.986	0.01
FKAB-1Gp	5	5.520	5.450	0.07
FKAB-1H	2	5.520	5.447	0.07
FKAB-1L	22	5.000	5.207	-0.21
FKAB-4	1	0.000	0.003	0.00
WRFK-1	5	5.000	5.047	-0.05
WRFK-2	8	5.000	5.053	-0.05
WRFK-3	1	4.000	3.939	0.06
WRFK-4	10	5.000	5.027	-0.03
WRFK-5	17	4.520	4.431	0.09

Figure 7 shows the SA QSAR model with observed bioactivity versus the predicted bioactivity.

The *Mycobacterium ranae* QSAR model is described by the following equation:

$$\begin{aligned} \text{MR Predicted Activity} = & -0.0083585 * \text{"Conformer Energy"} + 2.05758 * \text{"Fcharge"} + \\ & 5.3259\text{e-}05 * \text{"Apol"} + 0.0061422 * \text{"Dipole-mag"} - 0.023941 * \text{"Jurs-PPSA-1"} - \\ & 0.008252 * \text{"Jurs-PNSA-1"} + 5.5381\text{e-}05 * \text{"Jurs-PPSA-2"} + 0.00018566 * \text{"Jurs-PNSA-2"} \\ & - 18.282 * \text{"Jurs-FPSA-1"} + 13.321 * \text{"Jurs-FNSA-3"} - 8.46841 * \text{"Jurs-RPCG"} + \\ & 66.6262 * \text{"Jurs-RNCG"} + 0.052889 * \text{"Jurs-TPSA"} - 96.9761 * \text{"Jurs-RPSA"} + 96.9761 \\ & * \text{"Jurs-RASA"} - 127.577 * \text{"Density"} + 0.768698 * \text{"Hbond acceptor"} - 0.498282 * \end{aligned}$$

"Hbond donor" - 0.060764 * "Rotlbonds" - 0.075759 * "AlogP" + 0.337835 *
 "RadOfGyration" + 110.841

The final *Mycobacterium ranae* QSAR model with the selected conformers, predicted bioactivities, and residual values is presented in Table 21.

Table 21. Predictive *Mycobacterium ranae* QSAR Model selected conformers, predicted Bioactivities, and residual prediction errors

AMP ID	Conformer #	Actual Bioactivity	Predicted Bioactivity	Residual of Predicted Bioactivity
FKAB-1F	1	4.520	4.463	0.057
FKAB-1G	9	5.000	4.883	0.117
FKAB-1Ga	2	5.000	4.940	0.060
FKAB-1Gb	8	5.520	5.554	-0.034
FKAB-1Gc	10	4.520	4.552	-0.032
FKAB-1Gc1	1	5.520	5.528	-0.008
FKAB-1Gd	21	5.000	5.239	-0.239
FKAB-1Gd1	4	6.000	6.024	-0.024
FKAB-1Gd2	25	5.520	5.306	0.214
FKAB-1Gd3	6	5.520	5.572	-0.052
FKAB-1Ge	23	5.520	5.542	-0.022
FKAB-1Gf	13	4.000	4.081	-0.081
FKAB-1Gf1	22	4.000	3.907	0.093
FKAB-1Gg	1	4.520	4.442	0.078
FKAB-1Gg1	12	4.520	4.577	-0.057
FKAB-1Gh	24	5.000	5.059	-0.059
FKAB-1Gi	7	5.520	5.346	0.174
FKAB-1Gj	1	5.000	5.023	-0.023
FKAB-1Go	3	5.520	5.556	-0.036
FKAB-1Gp	11	5.000	5.014	-0.014

FKAB-1H	4	5.000	4.875	0.125
FKAB-1L	5	5.000	5.201	-0.201
FKAB-4	27	0.000	-0.002	0.002
WRFK-2	1	0.000	-0.020	0.020
WRFK-5	9	0.000	0.058	-0.058

Figure 8 shows the MR QSAR model with observed bioactivity versus the predicted bioactivity.

Computation of Descriptor Significance Percentage (DSP)

The values and sign of the QSAR equation coefficients provide a qualitative insight in the correlation of the physicochemical properties with biological activity. The quantitative contribution of any physicochemical property to the bioactivity of the compound is judged from both the respective QSAR equation coefficient and the value of the descriptor quantifying the property. The product of the QSAR coefficients and the respective descriptor mean value

$$(\text{Descriptor_Mean} = \Sigma \text{Descriptor_values_all_training_set_compounds} / 30)$$

would provide the contribution value of that descriptor to the overall bioactivity (Contribution_to_BioActivity – CtoBA).

$$\text{CtoBA} = \text{QSAR_Coefficient} * \text{Descriptor_mean_value}$$

The significance of CtoBA of any descriptor vis-à-vis the CtoBA of all the other descriptors can be computed by dividing the individual CtoBA by the sum total of all the CtoBA of all descriptors. The percentage value of this quotient is termed as 'Descriptor Significance Percentage – DSP'.

$$\text{DSP} = (\text{CtoBA} * 100) / \Sigma \text{abs}(\text{CtoBA})$$

The DSP values would provide a better insight in the quantitative contributions of the descriptors to the bioactivities of the compounds. The QSAR coefficients for the SA and

MR QSAR model, CtoBA, and DSP values are presented in Table 22 and Table 23 respectively.

Table 22. Computation of Descriptor Significance Percentage (DSP) for *Staphylococcus aureus* QSAR Model

Descriptor Name	<i>Staphylococcus aureus</i> QSAR Model Predicted Bioactivity	Mean Values of Descriptors of all compounds (MVD)	Contribution of Descriptor to BioActivity = Coefficient * Descriptors Mean (CtoBA)	Absolute Coefficient * (Mean)	Descriptor Significance Percentage DSP = $\frac{\text{CtoBA} * 100}{\text{Sum_Of_All_CtoBA}}$	Abs(DSP)
AlogP	0.115	-2.694	-0.309	0.309	-0.026	0.026
Density	-183.990	1.052	-193.628	193.628	-16.010	16.010
Dipole-mag	0.010	199.158	1.955	1.955	0.162	0.162
Fcharge	-1.496	6.000	-8.976	8.976	-0.742	0.742
Hbond acceptor	1.034	22.345	23.104	23.104	1.910	1.910
Hbond donor	0.039	34.517	1.362	1.362	0.113	0.113
Jurs-DPSA-2	0.00037	101316.629	37.405	37.405	3.093	3.093
Jurs-DPSA-3	0.00150	429.447	0.645	0.645	0.053	0.053
Jurs-FNSA-3	120.432	-0.043	-5.157	5.157	-0.426	0.426
Jurs-FPSA-1	438.251	0.810	354.927	354.927	29.347	29.347

Jurs-FPSA-3	267.258	0.077	20.664	20.664	1.709	1.709
Jurs-PNSA-1	0.188	679.305	127.469	127.469	10.540	10.540
Jurs-PNSA-2	0.00217	16233.835	-35.205	35.205	-2.911	2.911
Jurs-PPSA-1	0.00233	2881.175	6.713	6.713	0.555	0.555
Jurs-RASA	125.513	0.760	95.372	95.372	7.886	7.886
Jurs-RPCG	-715.316	0.012	-8.784	8.784	-0.726	0.726
Jurs-RPCS	-12.865	0.118	-1.522	1.522	-0.126	0.126
Jurs-RPSA	-125.513	0.240	-30.141	30.141	-2.492	2.492
Jurs-SASA	0.014	3560.480	49.822	49.822	4.120	4.120
Jurs-TASA	-0.066	2715.292	-178.536	178.536	-14.762	14.762
RadOfGyratio n	-0.100	15.399	-1.541	1.541	-0.127	0.127
Rotlbonds	-0.307	85.276	-26.167	26.167	-2.164	2.164
QSAR Coefficient		-225.589				

Table 23. Computation of Descriptor Significance Percentage (DSP) for
Mycobacterium ranae QSAR Model

Descriptor Name	<i>Mycobacterium ranae</i> QSAR Model Predicted Bioactivity	Mean Values of Descriptors of all compounds (MVD)	Contribution of Descriptor to BioActivity = Coefficient * Descriptors Mean (CtoBA)	Absolute (Coefficient * Mean)	DSP = CtoBA * 100/Sum_Of_All_CtoBA	Abs(DSP)
AlogP	-0.076	-2.951	0.224	0.224	0.051	0.051
Apol	0.000	93855.529	4.999	4.999	1.148	1.148
Conformer Energy	-0.008	-19.432	0.162	0.162	0.037	0.037
Density	-127.577	1.051	-134.041	134.041	-30.784	30.784
Dipole-mag	0.006	211.567	1.299	1.299	0.298	0.298
Fcharge	2.058	6.120	12.592	12.592	2.892	2.892
Hbond acceptor	0.769	21.120	16.235	16.235	3.729	3.729
Hbond donor	-0.498	34.120	-17.001	17.001	-3.905	3.905
Jurs-FNSA-3	13.321	-0.042	-0.555	0.555	-0.127	0.127
Jurs-FPSA-1	-18.282	0.812	-14.844	14.844	-3.409	3.409
Jurs-PNSA-1	-0.008	656.338	-5.416	5.416	-1.244	1.244
Jurs-PNSA-2	0.000	-14815.738	-2.751	2.751	-0.632	0.632

Jurs-PPSA-1	-0.024	2818.021	-67.466	67.466	-15.494	15.494
Jurs-PPSA-2	0.000	79913.288	4.426	4.426	1.016	1.016
Jurs-RASA	96.976	0.756	73.270	73.270	16.827	16.827
Jurs-RNCG	66.626	0.026	1.740	1.740	0.400	0.400
Jurs-RPCG	-8.468	0.012	-0.105	0.105	-0.024	0.024
Jurs-RPSA	-96.976	0.244	-23.706	23.706	-5.444	5.444
Jurs-TPSA	0.053	841.186	44.489	44.489	10.218	10.218
RadOfGyration	0.338	15.003	5.068	5.068	1.164	1.164
Rotlbonds	-0.061	82.840	-5.034	5.034	-1.156	1.156
QSAR Coefficient		110.841				

Comparison of SA and MR QSAR models: Insights in mechanism of action

The sixteen physicochemical properties common to the SA and MR QSAR models are shown in Table 24. The six physicochemical properties specific to the SA QSAR model are Jurs-FPSA-3, Jurs-RPCS, Jurs-DPSA-2, Jurs-DPSA-3, Jurs-SASA and Jurs-TASA. While the five physicochemical properties specific to the MR QSAR model are Apol, Conformer Energy, Jurs-PPSA-2, Jurs-RNCG, and Jurs-TPSA. The commonality of physicochemical properties show the minimal requirement for activity against SA and MR. The physicochemical properties such as Dipole-mag, Fcharge, Jurs-FNSA-3, Jurs-RPSA, Jurs-FPSA-1, Jurs-PNSA-1, Jurs-PNSA-2, Jurs-PPSA-1, and Jurs-RPCG indicate the importance of electrostatic potential for the AMPs bioactivity. While the physicochemical properties such as Density, H-bond acceptor, Jurs-RASA, H-bond donor, RadOfGyration, and Rotlbonds indicate the significance of the AMP molecular shape (appropriate conformation) for bioactivity. The importance of amphiphilicity is alluded to by the physicochemical properties such as Jurs-RASA, Jurs-RPSA, and AlogP. The magnitude order sorted DSP for the SA QSAR model is presented in Table 25. The top six DSP viz. Jurs-FPSA-1 (29.35), Density (-16.01), Jurs-TASA (-14.76), Jurs-PNSA-1 (10.54), Jurs-RASA (7.89), and Jurs-SASA (4.12) account for 82% of the SA predicted activity.

Table 24: A Rank ordering of the Physicochemical Properties defining anti-bacterial activity

Physico-chemical property	<i>Staphylococcus aureus</i> QSAR_DSP	Physico-chemical property	<i>Mycobacterium ranae</i> QSAR_DSP
Jurs-FPSA-1	29.347	Density	-30.784
Density	-16.01	Jurs-RASA	16.827
Jurs-TASA	-14.762	Jurs-PPSA-1	-15.494
Jurs-PNSA-1	10.54	Jurs-TPSA	10.218
Jurs-RASA	7.886	Jurs-RPSA	-5.444

Jurs-SASA	4.12	Hbond donor	-3.905
Jurs-DPSA-2	3.093	Hbond acceptor	3.729
Jurs-PNSA-2	-2.911	Jurs-FPSA-1	-3.409
Jurs-RPSA	-2.492	Fcharge	2.892
Rotlbonds	-2.164	Jurs-PNSA-1	-1.244
Hbond acceptor	1.91	RadOfGyration	1.164
Jurs-FPSA-3	1.709	Rotlbonds	-1.156
Fcharge	-0.742	Apol	1.148
Jurs-RPCG	-0.726	Jurs-PPSA-2	1.016
Jurs-PPSA-1	0.555	Jurs-PNSA-2	-0.632
Jurs-FNSA-3	-0.426	Jurs-RNCG	0.4
Dipole-mag	0.162	Dipole-mag	0.298
RadOfGyration	-0.127	Jurs-FNSA-3	-0.127
Jurs-RPCS	-0.126	AlogP	0.051
Hbond donor	0.113	Conformer	0.037
Jurs-DPSA-3	0.053	Jurs-RPCG	-0.024
AlogP	-0.026	Jurs-DPSA-2	0

To study the significance of electrostatics and sterics in the SA activity, the inventors selected five representative AMPs from each activity class as follows. The inventors chose FKAB-1G from 3 μ M, FKAB-1Go from 10 μ M, FKAB-1Gb from 30 μ M, FKAB-1Gd from 100 μ M, and FKAB-1Gg from inactive activity classes respectively. The Delphi spectrum electrostatic potential surface of these AMPs shown in Figure 9 and Figure 10 indicate that all AMPs have a distinct non-polar face and polar face. The correlation of non-polar surface area to bioactivity is seen from the descriptors Jurs – Total Hydrophobic Surface Area (Jurs-TASA) with -14.76% DSP contribution and Jurs – Relative Hydrophobic Surface Area (Jurs-RASA) with 7.89% DSP contribution. The 180 degrees opposite face of all the AMPs is presented in Figure 10. The active AMPs (p(MIC) < 100) show more polar surface area than the inactive AMP FKAB-1Gg. The

high polar surface area correlation with bioactivity is shown by the Jurs – Fractional Positive Surface Area – 1 (Jurs-FPSA-1) with 29.4% DSP contribution and Jurs – Partial Negatively charged Surface Area – 1 (Jurs-PNSA-1) with 10.5% DSP contribution. The shape of the AMPs is critical for bioactivity as is seen in Figure 9 and Figure 10. An open helical shape is required for activity. A globular shape as that of FKAB-1Gg relates to loss of SA bioactivity. The shape correlation to bioactivity is illustrated by the descriptor Density with –16.01% DSP contribution and Jurs – Sum of Solvent Accessible Surface Area (Jurs-SASA) with 4.12% DSP contribution.

The magnitude order sorted DSP for the MR QSAR model is presented in Table 26. The significant descriptors accounting for 82% of MR predicted activity are Density (-30.78), Jurs-RASA (16.83), Jurs-PPSA-1 (-15.49), Jurs-TPSA (10.22), Jurs-RPSA (-5.44), and H-bond donor (-3.91%). The inventors demonstrate the implication of electrostatics, sterics, hydrophobicity, and hydrophilicity in Figure 11 to Figure 14 for four representative AMPs from each activity class. The inventors selected FKAB-1Ge for 3 μ M, FKAB-1Gj for 10 μ M, FKAB-1Gg for 30 μ M, and FKAB-1Gfl for 100 μ M activity classes respectively. The Delphi electrostatic surface potential maps of the AMPs are presented in Figure 11 and Figure 12. All of the AMPs show a fairly good non-polar face and a very polar 180 degrees opposite face giving them the required amphipathic character. The correlation of the polar surface area to the MR bioactivity is evident from the descriptors Jurs-Sum of Solvent Accessible Surface Area of all Partially Positively charged Atoms (Jurs-PPSA-1) with –15.5% DSP contribution, Jurs – Total Polar Surface Area (Jurs-TPSA) with 10.5% DSP contribution and Jurs – Relative Polar Surface Area (Jurs-RPSA) with –5.44% DSP contribution. Mycobacterium is reported to be surrounded by a mycolate (thick waxy coat) or lipid layer, which is very hydrophobic in nature. Thus, the membrane disruption of the mycolate layer would necessitate hydrophobic nature for the AMPs. The hydrophobic hydrophilic surface potential map of the selected AMPs is shown in Figure 13 and Figure 14. The hydrophobicity, hydrophilicity correlation with the MR bioactivity is shown by the descriptors Jurs-Relative Hydrophobic Surface Area (Jurs-RASA) with 16.8% DSP contribution, and H-bond donor with –3.9% DSP

contribution. The contribution of shape to MR predicted bioactivity comes from the descriptor Density with -30.78% DSP contribution.

Table 25. *Staphylococcus aureus* Magnitude order descriptor significance percentage (DSP)

Physico-chemical property	<i>Staphylococcus aureus</i> QSAR_DSP
Jurs-FPSA-1	29.347
Density	-16.010
Jurs-TASA	-14.762
Jurs-PNSA-1	10.540
Jurs-RASA	7.886
Jurs-SASA	4.120
Jurs-DPSA-2	3.093
Jurs-PNSA-2	-2.911
Jurs-RPSA	-2.492
Rotlbonds	-2.164
Hbond acceptor	1.910
Jurs-FPSA-3	1.709
Fcharge	-0.742
Jurs-RPCG	-0.726
Jurs-PPSA-1	0.555
Jurs-FNSA-3	-0.426
Dipole-mag	0.162
RadOfGyration	-0.127

Jurs-RPCS	-0.126
Hbond donor	0.113
Jurs-DPSA-3	0.053
AlogP	-0.026
Apol	0.000
Conformer Energy	0.000
Jurs-PPSA-2	0.000
Jurs-RNCG	0.000
Jurs-TPSA	0.000

Table 26. *Mycobacterium ranae* Magnitude order descriptor significance percentage (DSP)

Physico-chemical property	<i>Mycobacterium ranae</i> QSAR_DSP
Density	-30.784
Jurs-RASA	16.827
Jurs-PPSA-1	-15.494
Jurs-TPSA	10.218
Jurs-RPSA	-5.444
Hbond donor	-3.905
Hbond acceptor	3.729
Jurs-FPSA-1	-3.409
Fcharge	2.892
Jurs-PNSA-1	-1.244
RadOfGyration	1.164

Rotlbonds	-1.156
Apol	1.148
Jurs-PPSA-2	1.016
Jurs-PNSA-2	-0.632
Jurs-RNCG	0.400
Dipole-mag	0.298
Jurs-FNSA-3	-0.127
AlogP	0.051
Conformer Energy	0.037
Jurs-RPCG	-0.024
Jurs-DPSA-2	0.00
Jurs-DPSA-3	0.00
Jurs-FPSA-3	0.00
Jurs-RPCS	0.00
Jurs-SASA	0.00
Jurs-TASA	0.00

QSAR Models Validation

Internal validation tests

Internal validation (cross-validation) tests of selected QSAR models (see Table 27) were performed at two levels. Both of the models showed $q^2_{LOO} > 0.83$ for the leave-one-out cross-validation tests. For the leave-10%-out (leave-three-out) cross-validation tests, SA model showed q^2_{L100} of 0.875, whereas MR model showed q^2_{L100} values of 0.537.

Table 27. Statistical model validation data of *Mycobacterium ranae* (MR)and *Staphylococcus aureus* (SA) QSAR Model

Internal Validation Tests Result

Tests	Model	MR	SA
Leave-one-out	q^2	0.997	0.839
	PRESS	0.2405	22.9249
Leave-10%-out (100 trials)	q^2	0.537	0.875
	PRESS	33.6103	17.8572

Randomization Tests

99 trails at 99% confidence level

((# Random r) >= (non-Random r)) = 0

Model	MR	SA
r from non-Random	0.9982	0.9877
Mean value of r from Random trials	0.61649	0.57241
Std deviation of Random trial	0.41594	0.39727

QSAR model validation by randomization tests

It is known that even with large number of observations and fewer terms, the QSAR models can be poorly predictive. Thus, with fewer observations (in this study twenty-five AMPs) and many more terms (in this study fifty descriptors and down selected to twenty-three), the QSAR models are prone to chance correlation. In the randomization test, the dependent variables (bioactivity values) are randomly reassigned to different compounds and new regression models are recomputed. This process is repeated several times. If the statistical data of these randomized models is comparable to the developed QSAR model, then the QSAR model developed is not predictive and the number of observations is insufficient. The inventors performed randomization tests of ninety-nine trials each at 99% confidence level for SA and MR QSAR models. The results of the randomization tests are presented in Table 27. The best mean random r value obtained for SA model is 0.572 ($r^2 = 0.327$), and MR model is 0.617 ($r^2 = 0.380$). The best random r value possible (based on the standard deviation) is about 0.730 ($r^2 = 0.533$) for the SA model and about 0.789 ($r^2 = 0.622$) for the MR model. These correlation coefficient values are far lower than the non-Random r values of 0.98 ($r^2 = 0.96$), thus indicating that the SA and MR QSAR models are not obtained by chance.

ANALYSIS AND DISCUSSION

The two major structural variables in this study are 1) the Tic-Oic dipeptide and 2) the spacers A and B. The Tic-Oic dipeptide unit, which is critical for antibacterial activity, exhibits the greatest effect on the physicochemical properties *via* the following descriptors. A) Electrostatic potential: Dipole-mag, Jurs-FNSA-3, Jurs-PNSA-1, Jurs-PNSA-2; B) Molecular shape: H-bond donor, RadOfGyration, Rotlbonds; C) Amphipathicity: Jurs-RPSA, AlogP. As previously stated, the physicochemical properties such as Dipole-mag, Fcharge, Jurs-FNSA-3, Jurs-RPSA, Jurs-FPSA-1, Jurs-PNSA-1, Jurs-PNSA-2, Jurs-PPSA-1, and Jurs-RPCG indicate the importance of electrostatics for the AMP bioactivity, while the physicochemical properties such as Density, H-bond acceptor, Jurs-RASA, H-bond donor, RadOfGyration, and Rotlbonds

indicate the significance of the AMP molecular shape for bioactivity. The importance of amphipathicity is alluded to by the physicochemical properties such as Jurs-RASA, Jurs-RPSA, and AlogP. The calculated values for these descriptors for each of the salient compounds are given in Table 28. Compound 25 was selected based on its broad spectrum activity (activity against *Staphylococcus aureus* ME/GM/TC resistant at 3 μ M and *Mycobacterium ranae* at 10 μ M concentration coupled with relatively low hemolytic activity at 14%) as the reference compound for this investigation. In addition the % deviation ($\Delta\%$) from the value for compound 25 and a % range ($\Delta\%$ range) deviation for the series of compounds is also given. The effect of deleting either the Tic or Oic residue on the conformational flexibility of the resulting peptide is shown in Figure 17.

The effect of Spacers A and B on the physicochemical properties *via* various descriptors maybe summarized as follows. A) Electrostatic potential: Dipole-mag, Jurs-FNSA-3, Jurs-RPSA, Jurs-PNSA-1, Jurs-PNSA-2, Jurs-PPSA-1; B) Molecular shape: Rotlbonds; C) Amphipathicity: Jurs-RPSA, AlogP. The calculated values for these descriptors for each of the salient compounds are given in Table 29. The physicochemical properties and the descriptors most affected by Spacers A and B are clearly evident in the analogs shown in Table 30. The effect of varying the lengths of Spacers A and B on the conformational flexibility of the resulting peptide is shown in Figure 18.

The 3D-QSAR also accurately predicts the effect of positive charge at both the C and N-terminus plays an effect on organism selectivity. Analysis of the data indicated that Compound 25 is significantly more active against SA than compound 28, while the activity of compounds 25 and 28 are identical against MR. Compound 28 has a free amine and thus a positive charge at the N-terminus while in compound 25 the amine is acetylated. The presence of a positive charge at the N-terminus reduces the activity from 3 μ M (compound 25) to 10 μ M (compound 28). Extending this logic to include compound 29 which differs from compound 25 by a having the free amine and a K residue (which introduces two positive charges at the N-terminus) reduces the activity even more to 30 μ M. The effect of positive charge on bioactivity of SA QSAR model is

about 34% {predominately from Jurs-FPSA-1 (29%), Jurs-DPSA-2 (3%) & Jurs-FPSA-3 (2%)}, whereas the effect of positive charge on bioactivity of MR QSAR model is only about 19% {predominately from Jurs-PPSA-1 (15%), Jurs-FPSA-1 (3%) & Jurs-PPSA-1 (1%)}. Thus, the effect a positive charge on bioactivity of SA is almost twice of the same on MR. This data and results explain the difference in activity of Compound 25 and Compounds 28 and 29 with respect to SA and the identical activity of the same compounds with respect to MR.

Increasing the number of Lys residues at the C-terminus also plays a role in organism selectivity. Compound 30 has four K residues at the C-terminus with a MR activity of 30 μ M, compound 40, with six K residues at the C-terminus with a MR activity of 3 μ M. The same trend holds true for compounds 31 and 42. Compound 31 has four K residues at the C-terminus with a MR activity of 10 μ M and compound 42 has five K residues at the C-terminus with a MR activity of 3 μ M. As can be seen from Table 30 the physicochemical properties Jurs-FPSA-1 and Density cause an increase in the SA bioactivity from compound 30 to compound 40, but physicochemical properties Jurs-TASA and Jurs-PNSA-1 cause a decrease in the SA bioactivity from compound 30 to compound 40. Thus, this cancellation effect is manifested in the equal activity of compound 30 and compound 40 against SA. As can be seen from the above Table 31 the physicochemical properties Density, Jurs-RASA and Jurs-TPSA-1 cause an increase in the MR bioactivity from compound 30 to compound 40, but physicochemical properties Jurs-PPSA-1 causes only a marginal decrease in the MR bioactivity from compound 30 to compound 40. Thus, the net effect is manifested in the increased bioactivity of compound 40 as compared to compound 30 against SA. In summary, even a small change such as addition of a single Lys has an effect on all the physicochemical properties of the peptide. The cumulative effect of this difference in physicochemical properties results in the large differences in observed bioactivity as shown by the example of compound 30 and compound 40.

Recently, Meroueh *et al*⁸⁸ reported the three-dimensional structure of bacterial cell wall peptidoglycan of *SA*, which concurs with the previously reported observations that the *SA* peptidoglycan outer layer is distinctly anionic⁸⁹. Thus, for the electrostatic interactions occurring between the target (*SA*) cell's membrane and the peptide determines organism potency, and it is a necessary condition for any active AMP to provide a complimentary polar face for the initial electrostatic attraction. The ESP maps of the inner faces of the hexagonal units of *SA* cell membrane (Figure 19A, 19B and 19C) show that about half of the inner surface is distinctly polar, while the opposite half is distinctly non-polar. This figure illustrates two major points: 1) the peptidoglycan presents a highly charged polar face to the approaching AMP and 2) once bound to the surface, the peptidoglycan presents an amphipathic pore to the AMP which is very complimentary to its own amphipathic character. Also, it is known that *SA* outer cell membrane pore size measures $\sim 70\text{-}100 \text{ \AA}$ ⁸⁸ and we have found that the largest dimension of these bioactive AMPs is about $30\text{-}40 \text{ \AA}$. Thus, one can rationally speculate that this amphipathic pore may play a role in transporting AMPs through the peptidoglycan layer to the lipid bilayer of the membrane propelled by the complementarity of electrostatics between AMPs and the *SA* peptidoglycan layer.

Table 28: Calculated Descriptor most Affected by the Tic-Oic dipeptide unit.

Compound /Property	Compound 25 FKAB-1G	Compound 33 FKAB-1Gf	Compound 36 FKAB-1Gfl	Compound 34 FKAB-1Gg	Compound 35 FKAB-1Ggl
ELECTROSTATIC POTENTIAL					
	value	value	value	value	value
	$\Delta\%$	$\Delta\%$	$\Delta\%$	$\Delta\%$	$\Delta\%$
Dipole-magnitude	269.60	251.73	273.75	81.00	297.77
	0	-6.6	+1.5	-69.95	+10.45
F-Charge	6.00	6.00	6.00	6.00	6.00
	0	0	0	0	0
Jurs-FNSA-3	-0.05	-0.06	-0.04	-0.03	-0.04
	0	20	-20	-40	-20
Jurs-RPSA	0.27	0.33	0.30	0.26	0.27
	0	+22.2	+11.1	3.7	0
Jurs-FPSA-1	0.82	0.83	0.82	0.81	0.78
	0	+1.2	0	-1.2	4.87
Jurs-PNSA-1	576.30	446.76	565.76	503.61	713.07
	0	-22.47	-1.8	-12.6	+23.7
Jurs-PNSA-2	-15950.51	-9781.01	-8051.80	-6499.05	-10525.42
	0	-38.67	-49.52	-59.2	-34.0
Jurs-PPSA-1	2672.17	2225.44	2513.86	2136.09	2459.00
	0	-16.7	-5.95	-20.06	-7.97
Jurs-RPCG	0.01	0.02	0.01	0.01	0.01
	0	100	0	0	100%
MOLECULAR SHAPE					
Density	1.05	1.03	1.05	1.06	1.07
	0	-1.9	0	+0.95	+1.9
H-bond acceptor	20.00	16.00	20.00	17.00	20.00
	0	-20	0	-15	0
Jurs-RASA	0.73	0.67	0.70	0.74	0.73
	0	-8.2	-4.1	+1.4	0
H-bond donor	32.00	32.00	36.00	32.00	35.00
	0	0	+12.5	0	+9.4
Rad-Of-Gyration	14.55	13.47	15.88	10.18	16.79
	0	-7.4	+9.1	-30.0	+15.39
Rotl-bonds	78.00	70.00	82.00	72.00	81.00
	0	-10.25	+5.1	-7.69	+3.85
					15.35%

AMPHIPHATICITY											
Jurs-RASA	0.73	0	0.67	-8.2	0.70	-4.1	0.74	+1.4	0.73	0	9.60%
Jurs-RPSA	0.27	0	0.33	+22.2	0.30	+11.1	0.26	-3.7	0.27	0	25.90%
AlogP	-3.25	0	-7.75	138	-12.05	270.7	-5.85	80	-9.08	179.3	270%

Table 29: Descriptors most Affected by Spacers A and B

Compound /Property	Compound 25 FKAB-1G		Compound 31 FKAB-1Gd		Compound 38 FKAB-1Gd1		Compound 39 FKAB-1Gd2		Compound 32 FKAB-1Ge		
	Value	Δ %	Value	Δ %	Value	Δ %	Value	Δ %	Value	Δ %	Δ % range
ELECTROSTATIC POTENTIAL											
Dipole-magnitude	269.596	0	222.841	-17.35	256.579	-4.82	220.357	-18.25	145.619	-45.99	45.99%
F-Charge	6.000	0	6.000	0	6.000	0	6.000	0	6.000	0	0%
Jurs-FNSA-3	-0.051	0	-0.050	-1.96	-0.056	+9.8	-0.045	-11.76	-0.026	-49.0	58.80%
Jurs-RPSA	0.274	0	0.239	-12.77	0.268	-2.19	0.228	-16.79	0.210	-23.36	23.36%
Jurs-FPSA-1	0.823	0	0.827	+0.49	0.805	-2.2	0.829	+0.73	0.834	+1.33	3.53%
Jurs-PNSA-1	576.297	0	608.270	+5.55	704.141	+22.18	634.863	+10.16	528.652	-8.27	30.45%
Jurs-PNSA-2	15950.000	0	-17351.269	+8.78	-19787.484	+24.055	-18648.209	+16.91	-6814.498	-57.27	81.33%
Jurs-PPSA-1	2672.174	0	2911.683	+8.94	2899.114	+8.5	3086.010	+15.5	2661.015	-0.415	15.50%
Jurs-RPCG	0.013	0	0.013	0	0.013	0	0.012	0	0.013	0	0%
MOLECULAR SHAPE											
Density	1.054	0	1.043	-1.0	1.047	-0.66	1.031	-2.18	1.042	-1.13	2.18%

H-bond	20.000	0	20.000	0	20.000	0	20.000	0	20.000	0	16.000	-20	20%
Jurs-RASA	0.726	0	0.761	+4.8	0.732	+0.83	0.772	+6.33	0.790	+8.8	8.80%		
H-bond donor	32.000	0	32.000	0	32.000	0	32.000	0	28.000	-12.5	12.50%		
Rad-Of-Gyration	14.550	0	13.153	-9.6	14.228	-2.2	14.161	-2.67	11.799	-18.9	18.90%		
Rotl-bonds	78.000	0	86.000	+10.25	82.000	+5.13	94.000	+20.52	66.000	-15.38	35.90%		
AMPHIPHATICITY													
Jurs-RASA	0.726	0	0.761	+4.8	0.732	+0.83	0.772	+6.33	0.790	+8.8	8.80%		
Jurs-RPSA	0.274	0	0.239	-12.77	0.268	-2.12	0.228	-16.79	0.210	-23.36	23.36%		
AlogP	-3.252	0	-1.520	53.26	-2.527	22.3	1.650	49.3	1.054	67.56	67.56%		

Table 30. Descriptors relating charge density with SA activity

Percent Contribution		+ 29%	- 16%	- 15%	+11%
Cmpd #	SA Activity	Jurs-FPSA-1	Density	Jurs-TASA	Jurs-PNSA-1
30	3	0.834	1.042	2520	528
40	3	0.837	1.037	2761	564
Effect on Bioactivity		Increase BA	Increase BA	Decrease BA	Decrease BA

Table 31. Descriptors relating charge density with MR activity

123

Percent Contribution		- 30%	+ 16%	- 15%	+10%
Cmpd #	MR Activity	Density	Jurs-RASA	Jurs-PPSA-1	Jurs-TPSA-1
30	30	1.043	0.791	2668.13	670.01
40 ⁹⁰	3	1.037	0.794	2919.12	717.85
Effect on Bioactivity		Increase BA	Increase BA	Decrease BA	Increase BA

The following references are cited above by number, and the entire contents of these and all references cited in this document are incorporated herein by reference.

REFERENCES:

1. Yeaman, M. R.; Yount, N. Y., Mechanisms of antimicrobial peptide action and resistance. *Pharmacological Reviews* **2003**, 55, (1), 27-55.
2. Dennison, S. R.; Wallace, J.; Harris, F.; Phoenix, D. A., Amphiphilic α -helical antimicrobial peptides and their structure/function relationships. *Protein and peptide Letters* **2005**, 12, 31-39.
3. Toke, O., Antimicrobial peptides; new candidates in the fight against bacterial infections. *Biopolymers* **2005**, 80, 717-735.
4. Ganz, T., Defensins: antimicrobial peptides of innate immunity. *Nature reviews, Immunology* **2003**, 3, 710-720.
5. Simmaco, M.; Mignogna, G.; Barra, D., Antimicrobial peptides from amphibian skin: what do they tell us? *Biopolymers* **1999**, 47, 435-450.
6. Hancock, R. E. W.; Lehrer, R., Cationic peptides: a new source of antibiotics. *Trends Biotechnol* **1998**, 16, 82-88.
7. Zasloff, M., Antimicrobial peptides of multicellular organisms. *Nature* **2002**, 415, 389-395.
8. Powers, J.-P. S.; Hancock, R. E. W., The relationship between peptide structure and antibacterial activity. *Peptides* **2003**, 24, 1681-1691.
9. Blondelle, S. E.; Lohner, K.; Aguilar, M.-I., Lipid-induced conformation and lipid-binding properties of cytolytic and antimicrobial peptide: determination and biological specificity. *Biochimica et Biophysica Acta* **1999**, 1462, 89-108.
10. Brogden, K. A., Antimicrobial peptides: pore formers or metabolic inhibitors of bacteria. *Nature Reviews Microbiol* **2005**, 3, 238-250.
11. Pouny, Y.; Rapaport, D.; Mor, A.; Nicolas, P.; Shai, Y., Interaction of antimicrobial dermaseptin and fluorescently labeled analogues with phospholipid membranes. *Biochemistry* **1992**, 31, 12416-12423.
12. Papo, N.; Shai, Y., Can we predict biological activity of antimicrobial peptides from their interaction with model phospholipid membranes? *Peptides* **2003**, 24, 1693-1703.
13. Bechinger, B., The structure, dynamics and orientation of antimicrobial peptides in membranes by multidimensional solid-state NMR spectroscopy. *Biochim. et Biophys. Acta* **1999**, 1462, 157-183.
14. Lee, M. T.; Chen, F. Y.; Haung, H. W., Energetics of pore formation induced by membrane active peptides. *Biochemistry* **2004**, 43, 3590-3599.

15. Bechinger, B., Solid-state NMR investigations of the interaction contributions that determine the alignment of helical polypeptides in biological membranes. *FEBS Lett.* **2001**, 504, 161-165.
16. Song, Y. M.; Park, Y.; Lim, S. S.; Yang, S.-T.; Woo, E.-R.; Park, S.; Lee, J. S.; Kim, J. I.; Hahm, K.-S.; Kim, Y.; Shin, S. Y., Cell selectivity and mechanism of action of antimicrobial model peptides containing peptoid residues. *Biochemistry* **2005**, 44, 12094-12106.
17. Giangaspero, A.; Sandri, L.; Tossi, A., Amphipathic α -helical antimicrobial peptides. *Eur. J. Biochem.* **2001**, 268, 5589-5600.
18. Glukhov, E.; Stark, M.; Burrows, L. L.; Deber, C. M., Basis for selectivity of cationic antimicrobial peptides for bacterial versus mammalian membranes. *J. Biol. Chem.* **2005**, 280, 33960-33967.
19. White, S. H.; Wimley, W. C., Hydrophobic interactions of peptides with membrane interfaces. *Biochim. Biophys. Acta* **1998**, 1376, (3), 339-352.
20. Situ, H.; Wei, G.; Smith, C. J.; Mashhoon, S.; Bobek, L. A., Human salivary MUC7 mucin peptides: effect of size, charge and cystine residues on antifungal activity. *Biochem. J.* **2003**, 375, 175-182.
21. Moerman, L.; Bosteels, S.; Noppe, W.; Willems, J.; Clynen, E.; Schoofs, L.; Thevissen, K.; Tytgat, J.; Van Elder, J.; van der Walt, J.; Verdonck, F., Antibacterial and antifungal properties of helical cationic peptides in the venom of scorpions from southern Africa. *Eur. J. Biochem.* **2002**, 269, 4799-4810.
22. Deslouches, B.; Phadke, S. M.; Lazarevic, V.; Cascio, M.; Islam, K.; Montelaro, R. C.; Mietzner, T. A., De novo generation of cationic antimicrobial peptides: influence of length and tryptophan substitution on antimicrobial activity. *Antimicrobial Agents and Chemotherapy* **2005**, 49, 316-322.
23. Wareham, D. W.; Bean, D. C., In vitro activity of polymyxin B in combination with imipenem, rifampicin and azithromycin versus multidrug resistant strains of *Acinetobacter baumannii* producing OXA-23 carbapenemases. *Ann. Clin. Microbiol. Antimicrob.* **2006**, 5, 10.
24. Zasloff, M., Antimicrobial peptides of multicellular organisms. *Nature* **2002**, 415, 389-395.
25. Wenk, M. R.; Seelig, J., Magainin-2-amide interaction with lipid membranes: calorimetric detection of peptide binding and pore formation. *Biochemistry* **1998**, 37, 3909-3916.
26. Yang, L.; Weiss, T. M.; Lehrer, R. I.; Huang, H. W., Crystallization of antimicrobial pores in membranes: magainin and protegrin. *Biochemical J.* **2000**, 79, 2002-2009.
27. Hicks, R. P.; Mones, E.; Kim, H.; Koser, B. W.; Nichols, D. A.; Bhattacharjee, A. K., Comparison of the conformation and electrostatic surface properties of magainin peptides bound to SDS and DPC micelles: Insight into possible modes on antimicrobial activity. *Biopolymers* **2003**, 68, 459-470.

28. Rozek, A.; Friedrich, C. L.; Hancock, R. E., Structure of the bovine antimicrobial peptide indolicidin bound to dodecylphosphocholine and sodium dodecyl sulfate micelles. *Biochemistry* **2000**, 39, 15765-15774.
29. Whitehead, T. L.; Jones, L. M.; Hicks, R. P., Effects of the incorporation of CHAPS into SDS micelles on neuropeptide-micelle binding: separation of the role of electrostatic interactions from hydrophobic interactions. *Biopolymers* **2001**, 58, (7), 593-605.
30. Whitehead, T. L.; Jones, L. M.; Hicks, R. P., PFG-NMR investigations of the binding of cationic neuropeptides to anionic and zwitterionic micelles. *J Biomol Struct Dyn* **2004**, 21, (4), 567-576.
31. Kyle, D. J.; Blake, P. R.; Smithwick, D.; Green, L. M.; Martin, J. A.; Sinsko, J. A.; Summers, M. F., NMR and computational evidence that high-affinity bradykinin receptor antagonists adopt C-terminal beta-turns. *J Med Chem* **1993**, 36, (10), 1450-60.
32. Hicks, R. P.; Bhonsle, J. B.; Venugopal, D.; Koser, B. W.; Magill, A. J., De Novo Design of Selective Antibiotic Peptides by Incorporation of Un-natural Amino Acids. *J. Med. Chem.* **2007**, 50, (13), 3026-3036.
33. Giacometti, A.; Cirioni, O.; Del Prete, M. S.; Paggi, A. M.; D'Errico, M. M.; Scalise, G., Combination studies between polycationic peptides and clinically used antibiotics against Gram-positive and Gram-negative bacteria. *Peptides* **2000**, 21, 1155-1160.
34. Grgurina, I.; Bensaci, M.; Pocsfalvi, G.; Mannina, L.; Cruciani, O.; Fiore, A.; Fogliano, V.; Sorensen, K. N.; Takemoto, J. Y., Novel cyclic lipodepsipeptide from *Pseudomonas syringae* pv. lachrymans strain 508 and Syringopeptin antimicrobial activities. *Antimicrobial Agents and Chemotherapy* **2005**, 49, (12), 5037-5045.
35. Lockwood, N. A.; Haseman, J. R.; Tirrell, M. V.; Mayo, K. H., Acylation of SC4 dodecapeptide increases bactericidal potency against Gram-positive bacteria, including drug-resistant strains. *Biochem. J.* **2004**, 378, 93-103.
36. Giacometti, A.; Cirioni, O.; Del Prete, M. S.; Barchiesi, F.; Paggi, A. M.; Petrelli, E.; Scalise, G., Comparative activities of polycationic peptides and clinically used antimicrobial agents against multidrug-resistant nosocomial isolates of *Acinetobacter baumannii*. *J. Antimicrobial Chemotherapy* **2000**, 46, 807-810.
37. Sklenar, M.; Piotto, M.; Leppik, R.; Saudek, V., Gradient-tailored water suppression for ^1H - ^{15}N HSQS experiments optimized to retain full sensitivity. *J. Magn. Res. Series A* **1993**, 102, 241.
38. Di Modugno, E.; Erbeti, I.; Ferrari, L.; Galassi, G.; Hammond, S. M.; Xerri, L., In vitro activity of the tribactam GV 104326 against Gram-Positive, Gram-Negative and anaerobic bacteria. *Antimicrobial Agents and Chemotherapy* **1994**, 38, 2362-2368.
39. Misiek, M.; Pursiano, T. A.; Leitner, F.; Price, K. E., Microbiological properties of a new cephalosporin, BL-S 339: 7-(phenylacetyl-imidoyl-aminoacetamido)-3-(2-methyl-1,3,4-thiadiazol-5-ylthiomethyl)ceph-3-em-4-carboxylic acid. *Antimicrobial Agents and Chemotherapy* **1973**, 3, 40-48.

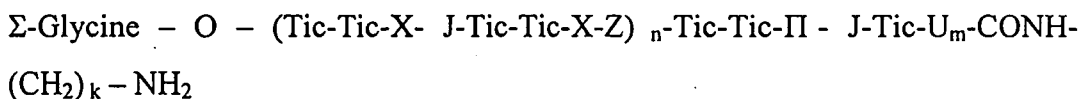
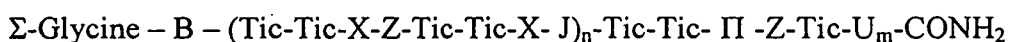
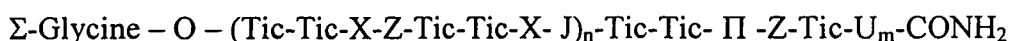
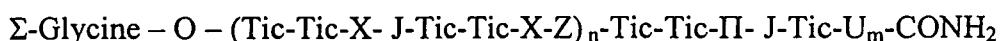
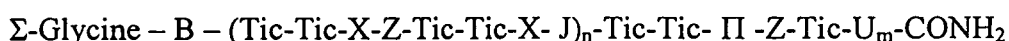
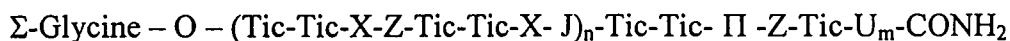
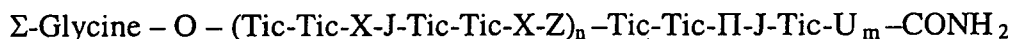
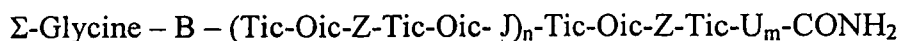
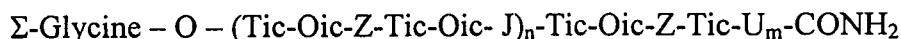
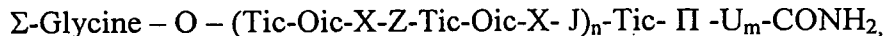
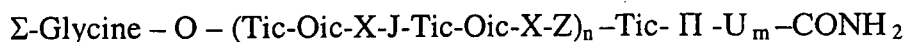
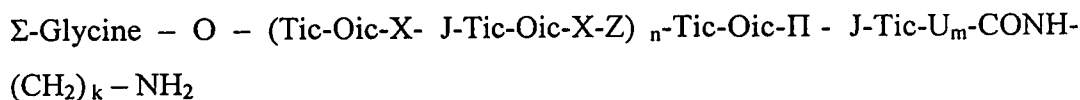
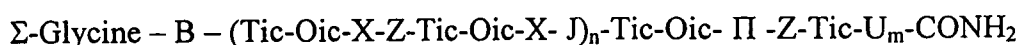
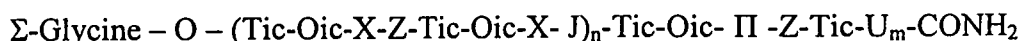
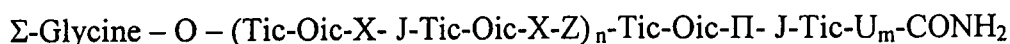
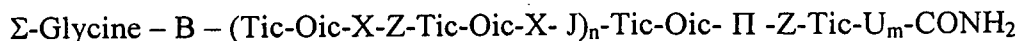
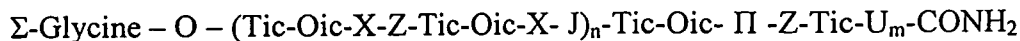
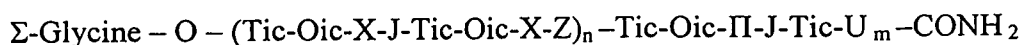
40. Edwards, J. R.; Turner, P. J.; Withnell, E. S.; Grindy, A. J.; Narin, K., In vitro antibacterial activity of SM-7338, a carbapenem antibiotic with stability to dehydropeptidase 1. *Antimicrobial Agents and Chemotherapy* **1989**, 33, (2), 215-222.
41. Montesinos, M. C.; Gadangi, P.; Longaker, M.; Sung, J.; Levine, J.; Nilsen, D.; Reibman, J.; Li, M.; Jiang, C.-K.; Hirschhorn, R.; Recht, P. A.; Ostad, E.; Levin, R. I.; Cronstein, B. N., Wound healing is accelerated by agonists of adenosine A₂ (G_{xs}-linked) receptors. *J. Exp. Med.* **1997**, 186, 1615-1620.
42. Grant, G. A., *Synthetic Peptides, A user's guide*. 2nd ed.; Oxford University Press: New York, NY, 2002.
43. Benoiton, N. L., *Chemistry of Peptide Synthesis*. Taylor and Francis (CRC Press): Boca-Raton, FL, 2006.
44. Schmidt, J. J.; Stafford, R. G.; Millard, C. B., High-throughput assays for botulinum neurotoxin proteolytic activity: serotypes A, B, D, and F. *Anal Biochem* **2001**, 296, (1), 130-7.
45. Ghose, A. K.; Crippen, G. M., Atomic physicochemical parameters for three-dimensional structure-directed quantitative structure-activity relationships. 2. Modeling dispersive and hydrophobic interactions. *Chem. Inf. Comput. Sci.* **1987**, 27, 21.
46. Ghose, A. K.; Crippen, G. M., Atomic physicochemical parameters for three-dimensional structure-directed quantitative structure-activity relationships. 1. Partition coefficients as a measure of hydrophobicity. *J. Comput. Chem.* **1986**, 7, 565.
47. Hansch, C., *Accounts of Chemical Research* **1969**, 2, 232-239.
48. Cramer, R. D. I.; E., P. D.; Bunce, J. D., *J. Am. Chem. Soc.* **1988**, 110, 5959-5967.
49. Hopfinger, A. J.; Burke, B. J., *Molecular shape analysis: a formation to quantitatively establish spatial molecular similarity*. Wiley: New York, 1990; p 173-209.
50. Klebe, G., *Perspectives in Drug Discovery and Design* **1998**, 12/13/14, 87-104.
51. Jain, A. N.; Dietterich, T. G.; Lathrop, R. H.; Chapman, D.; Critchlow, R. E. J., *J. Computer-Aided Mol. Design* **1994**, 8, 635-652.
52. Doweyko, A. M., *J. Math. Chem.* **1991**, 7, 273-285.
53. Wiener, H., *J. Am. Chem. Soc.* **1947**, 69, 17-20.
54. Bonchev, D., *Information theoretic indices for characterization of chemical structures*. 1983; Vol. 5, p 249.
55. Hosoya, H., *Bulletin of the Chemical Society of Japan* **1971**, (44), 2332-2339.
56. Kier, L. B.; Hall, L. H., *Molecular connectivity in chemistry and drug research*. Academic Press: New York, 1976; Vol. 14, p 257.
57. Kier, L. B., *Quantitative Structure-Activity Relationships* **1985**, 4, 109-116.
58. Kier, L. B.; Hall, L. H.; Frazer, J. W., *J. Math. Chem.* **1991**, 7, 229-241.
59. Balaban, A. T., *Chem. Phys. Letts* **1982**, 89, 399-404.
60. Bonchev, D.; Mekenyan, O.; Trinajstić, N., *J. Comp. Chem.* **1981**, 2, 127-148.
61. Marsili, M.; Gasteiger, J., Fast calculation of atomic charges from molecular topology and orbital electronegativities. *Studies in Physical and Theoretical Chemistry* **1981**, 16, 56-67.
62. Rohrbaugh, R. H.; Jurs, P. C., *Analytica Chimica Acta* **1987**, 199, 99-109.

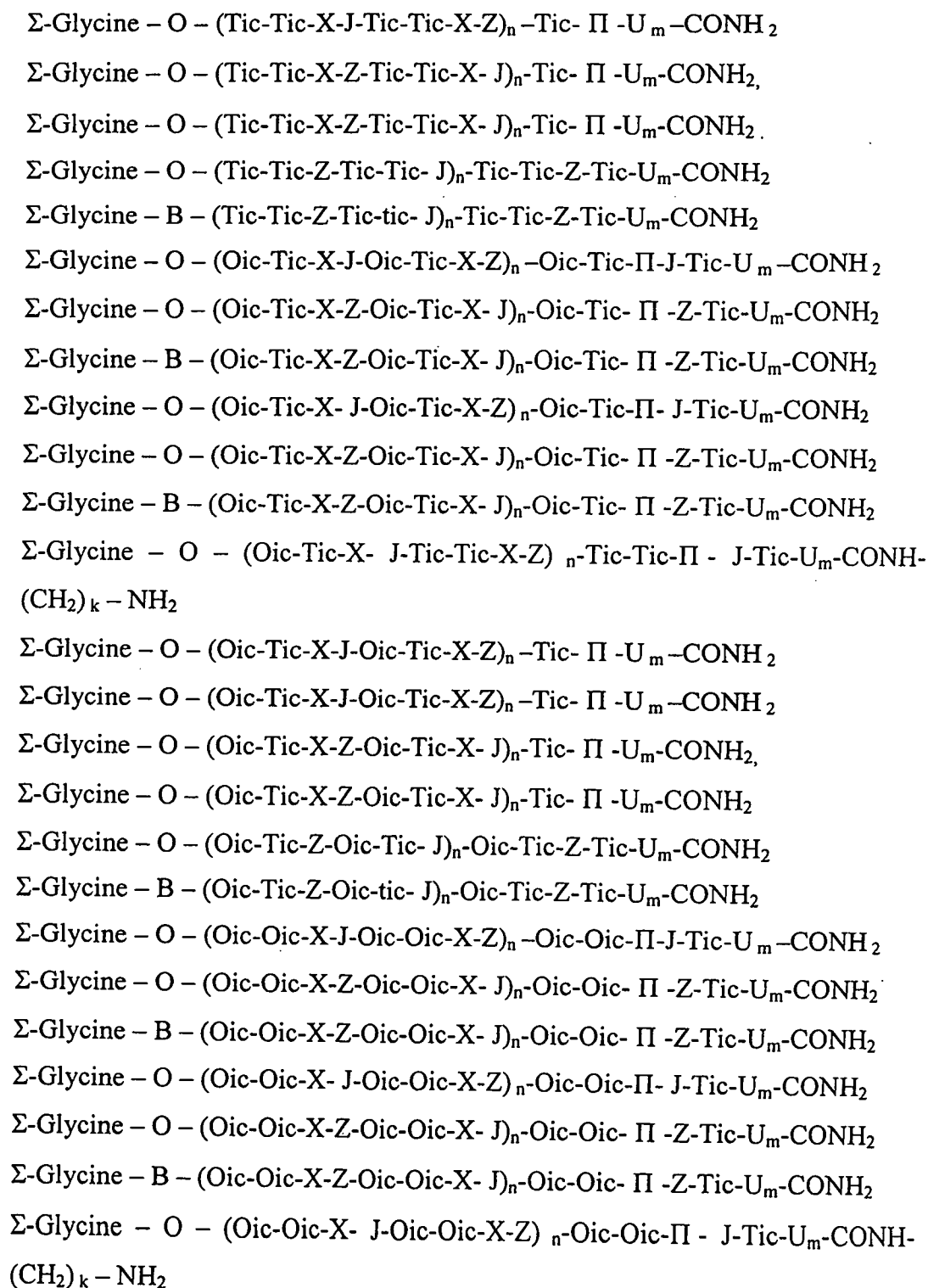
63. Stanton, D. T.; Jurs, P. C., *Anal. Chem.* **1990**, 62, 2323-2329.
64. Kharkar, P. S.; Desai, B.; Gaveria, H.; Varu, B.; Loriya, R., *J. Med. Chem.* **2002**, 45, 4858-4867.
65. Drew, M. G. B.; Wilden, G. R. H.; Spillane, W. J.; Walsh, R. M.; Ryder, C. A., *J. Agricultural and Food Chem.* **1998**, 46, 3016-3026.
66. Hirashima, A.; Rafaeli, A.; Gileadi, C.; Kuwano, E., *Bioorg. Med. Chem.* **1999**, 7, 2621-2628.
67. Hasegawa, K.; Arakawa, M.; Funatsu, K., Rational choice of bioactive conformations through use of conformation analysis and 3-way partial least squares modeling. *Chemometrics and Intelligent Lab. Sys.* **2000**, 50, (2), 252-261.
68. Hopfinger, A. J.; Wang, S.; Tokarski, J. S.; Jin, B.; Albuquerque, M., *J. Am. Chem. Soc.* **1997**, 119, 10509-10524.
69. Hasegawa, K.; Arakawa, M.; Funatsu, K., *Comput. Biol. Chem.* **2003**, 27, 211-216.
70. Vedani, A.; McMasters, D. R.; Dobler, M., *Quantitative Structure-Activity Relationships* **2000**, 19, 149-161.
71. Appell, M.; Dunn, W. J.; Reith, M. E. A.; Miller, L.; Flippen-Anderson, J. L., *Bioorganic & Med. Chem.* **2002**, 10, 1197-1206.
72. Xiao, Y.-D.; Hammond, P. S.; Harris, R.; SCHMITT, J. D.; Klucik, J., *J. Med. Chem.* **2004**, 47, 831-839.
73. Sulea, T.; Kurunczi, L.; Oprea, T. L.; Simon, Z., *J. Computer-Aided Mol. Design* **1998**, 12, 133-146.
74. Bhonsle, J. B.; Wang, Z. W.; Tamamura, H.; Fujii, N.; Peiper, S. C.; Trent, J. O., A simple, automated quasi-4D-QSAR, quasi-multi way PLS approach to develop highly predictive QSAR models for highly flexible CXCR4 inhibitor cyclic pentapeptide ligands using scripted common molecular modeling tools. *QSAR & Combinatorial Science* **2005**, 24, (5), 620-630.
75. Accelrys INC, ., Cerius2 Version 4.10, 9685 Scranton Road San Diego, CA 92121-3752. .
76. Bhonsle, J. B.; Bhattacharjee, A. K.; Gupta, R., Novel semi-automated methodology for developing highly predictive QSAR models: application for development of QSAR models for insect repellent amides. *J. Molecular Modeling* **2007**, 13, (1), 179-208.
77. Marsili, M.; Gasteiger, J., Fast calculation of atomic charges from molecular topology and orbital electronegativities. *Studies in Physical and Theoretical Chemistry* **1981**, 16, 56-67.
78. Mayo, S. L.; Olafson, B. D.; Goddard, W. A. I., DREIDING: A generic force field. *J. Phys. Chem.* **1990**, 94, 8897-8909.
79. Levitt, M.; Lifson, S., Refinement of protein conformations using a macromolecular energy minimization procedure. *J. Mol. Biol.* **1969**, 46, (2), 269-279.
80. Chang, G.; Guida, W. C.; Still, W. C., An internal-coordinate Monte Carlo method for searching conformational space. *J. Am. Chem. Soc.* **1989**, 111, 4379-4386.

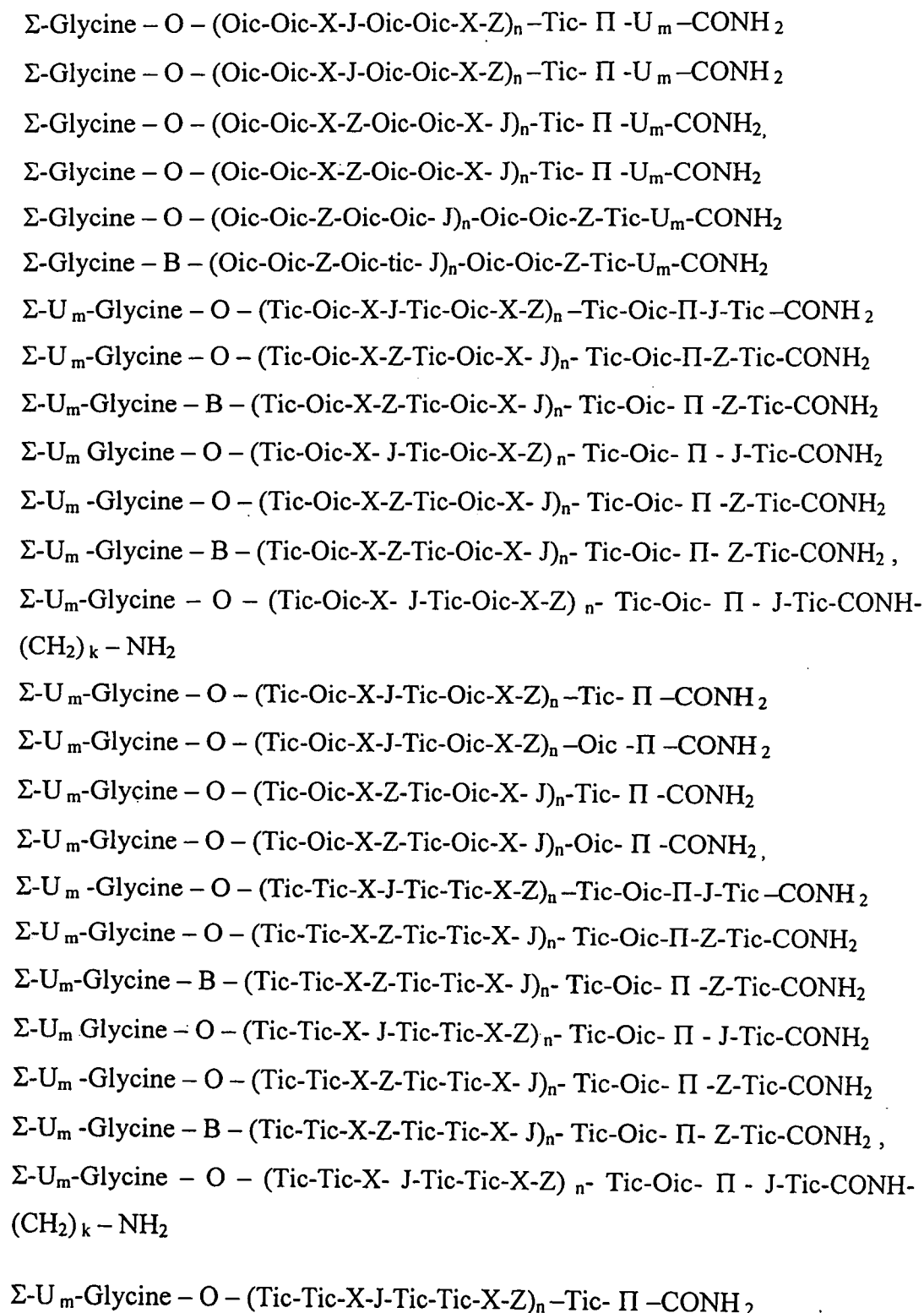
81. Bro, R., *J. Chemometrics* **1996**, 10, 47-61.
82. Hasegawa, K.; Arakawa, M.; Funatsu, K., 3D-QSAR study of insecticidal neonicotinoid compounds based on 3-way partial least squares model. *Chemometrics and Intelligent Lab. Sys.* **1999**, 47, 33-40.
83. Hill, T. L., An Introduction to statistical thermodynamics. In *An introduction to statistical thermodynamics*, Dover Publications: New York, 1960.
84. Dewar, M. J. S.; Thiel, W. J., *J. Am. Chem. Soc.* **1977**, 99, 4907.
85. Richon, A. B.; Young, S. S., An introduction to QSAR Methodology. *Network Science Corporation Saluda NC* **1997**.
86. Yao, S. W.; Lopes, V. H. C.; Fernandez, F.; Garcia-Mera, X.; Morales, M.; Rodriguez-Borges, J. E.; Corderio, M. N. D. S., Synthesis and QSAR study of the anticancer activity of some novel indane carbocyclic nucleosides. *Bioorganic & Med. Chem.* **2003**, 11, (23), 4999-5006.
87. *Sybyl Molecular Modeling System Version 6.9.1*, St. Louis, 2003.
88. Meroueh, S. O.; Bencze, K. Z.; Heseck, D.; Lee, M.; Fisher, J. F.; TStemmler, T. L.; Mobashery, S., Three-dimensional structures of bacterial cell wall peptidoglycan. **2006**, 103, (12), 4404-4409.
89. Hancock, R. E., Cationic antimicrobial peptides: toward clinical applications. *Expert Opin. Investig. Drugs* **2000**, 8, 1723-1729.
90. Atrih, A.; Zollner, P.; Allmaier, G.; Williamson, M. P.; Foster, S. J., Peptidoglycan structural dynamics during germination of *Bacillus subtilis* 168 Endospores. *J. Bacteriology* **1998**, 180, (17), 4603-4612.

CLAIMS:

1. A synthetic antimicrobial peptide analog having a formula selected from the group consisting of:







Σ -U_m-Glycine – O – (Tic-Tic-X-J-Tic-Tic-X-Z)_n–Oic –Π –CONH₂

Σ -U_m-Glycine – O – (Tic-Tic-X-Z-Tic-Tic-X- J)_n-Tic- Π –CONH₂, and

Σ -U_m-Glycine – O – (Tic-Tic-X-Z-Tic-Tic-X- J)_n-Oic- Π –CONH₂

wherein Tic stands for tetrahydroisoquinolinecarboxylic acid,

Oic stands for octahydroindolecarboxylic acid,

Σ is acetyl, NH₂, biotin, β-thienylalanine (Thi), cysteine, Keyhole Limpet Haemocyanin (KLH), or Bovine Serum Albumine (BSA).

U is lysine, arginine, histidine, ornithine, 2,3-diaminopropionic acid (Dpr), diaminobutanoic acid (Dab), 4-aminopiperidine-4-carboxylic acid (Apc4), or 3-aminopiperidine-3-carboxylic acid (Apc3),

X is glycine, alanine, β-alanine, gamma-aminobutyric acid (Gaba), ε-aminohexanoic acid (Ahx), phenylglycine (Phg), 9-aminooctanoic acid (9-Aoa), 10-aminodecanoic acid (10Ada), 12-aminododecanoic acid (12-Adda), or 16-aminopalmitic acid (16-Apa),

J is lysine, arginine, histidine, ornithine, 2,3-diaminopropionic acid (Dpr), or 2,4-diaminobutanoic acid (Dab),

Z is phenylalanine, tyrosine, tryptophan, 4-fluorophenylalanine (Fpa), 4-chlorophenylalanine (Cph), 4-nitrophenylalanine (Nph), phenyl glycine (Phg), valine, isoleucine, norvaline, norleucine, norisoleucine, 4-Aminobutyric acid, piperidinic acid, 6-Aminocaproic acid, 2-Aminoheptanoic acid, 2-Aminoisobutyric acid, 3-Aminoisobutyric acid, 2-Aminopimelic acid, 2,4-Diaminobutyric acid, N-Ethylglycine, allo-Isoleucine, N-Methylglycine, N-Methylisoleucine, or N-Methylvaline,

O is phenylalanine, leucine, valine or isoleucine,

B is lysine, arginine, histidine, ornithine, 2,3-diaminopropionic acid (Dpr), 2,4-diaminobutanoic acid (Dab), 4-aminopiperidine-4-carboxylic acid (Apc4), or 3-aminopiperidine-3-carboxylic acid (Apc3),

Π is glycine, alanine, β-alanine, gamma-aminobutyric acid (Gaba), or ε-Aminohexanoic acid (Ahx),

n is 1 to 4 repeating units,

m is 1 to 5 repeating units, and

k is 1 to 5 repeating units.

2. The antimicrobial peptide of claim 1, which in its secondary structure includes at least three β-turns and exhibits sufficient conformational flexibility to bind to the membrane of at least one of Gram positive bacteria, Gram negative bacteria or Mycobacterium.

3. The antimicrobial peptide of claim 1, which exhibits less hemolytic activity than naturally occurring non-selective antimicrobial peptides.

4. The antimicrobial peptide of claim 1, which is selected from the group consisting of

NH₂-GKGL-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GKR-

CONH₂

NH₂-GKGL-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-Oic-GKR-

CONH₂

NH₂-GKGL-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GLR-

CONH₂

NH₂-GKGL-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GLR-

CONH₂

NH₂-GKGL-Tic-Oic-FK-Tic-Oic-KF-Tic-Oic-FK-Tic-Oic-KF-Tic-Oic-FK-Tic-Oic-FKR-

CONH₂

NH₂-KL-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-Oic-KR-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH-CH₂-CH₂-NH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH-CH₂-CH₂-CH₂-NH₂

NH₂--GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂

NH₂--KL-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂

Ac-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-KKKK-CONH₂

Ac-Gaba-F-Tic-Oic-Gaba-K-Tic-Oic-Gaba-F-Tic-Oic-Gaba-K-Tic-KKKK-CONH₂

Ac-G-Tic-Oic-K-Tic-Oic-G-Tic-Oic-K-Tic-KKKK-CONH₂

Ac-GF-Oic-GK-Oic-GF-Oic-GKKKKK-CONH₂

Ac-GF-Tic-GK-Tic-GF-Tic-GK-Tic-KKKK-CONH₂

Ac-GF-Tic-G-GK-Tic-G-GF-Tic-G-GK-Tic-KKKK-CONH₂

Ac-GF-G-Oic-GK-G-Oic-GF-G-Oic-GK-G-KKKK-CONH₂

Ac-GF-F-Oic-GK-F-Oic-GF-F-Oic-GK-F-KKKK-CONH₂

Ac-βAla-F-Tic-Oic-βAla-K-Tic-Oic-βAla-F-Tic-Oic-βAla-K-Tic-KKKK-CONH₂

Ac-Ahx-F-Tic-Oic-Ahx-K-Tic-Oic-Ahx-F-Tic-Oic-Ahx-K-Tic-KKKK-CONH₂

Ac-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-KKKKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKKKK-CONH₂

Ac-Gaba-F-Tic-Oic-Gaba-K-Tic-Oic-Gaba-F-Tic-Oic-Gaba-K-Tic-KKKKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Orn-Orn-Orn-Orn-CONH₂

Ac-G-Fpa-Tic-Oic-GK-Tic-Oic-G-Fpa-Tic-Oic-GK-Tic-KKKK-CONH₂

Ac-GF-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-Orn-Orn-Orn-Orn-CONH₂

Biotin-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂

Ac-GF-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-Dpr-DprDpr-Dpr-CONH₂

Ac-βAla-Fpa-Tic-Oic-βAla-Dpr-Tic-Oic-βAla-Fpa-Tic-Oic-βAla-Dpr-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂

Ac-G-dF-Tic-Oic-GK-Tic-Oic-G dF-Tic-Oic-GK-Tic-KKKK-CONH₂

Ac-GF-Tic-Oic-G-dK-Tic-Oic-GF-Tic-Oic-G-dK-Tic-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂

(NH₂)₄ - (K)₂-K-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-CONH₂

Ac-G-Fpa-Tic-Oic-G-Dpr-Tic-Oic-G-Fpa-Tic-Oic-G-Dpr-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-βA-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Gaba-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Ahx-KKKK-CONH₂

Ac-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Dab-Dab-Dab-Dab-CONH₂

Ac-GF-Tic-Oic-G-Tic-Oic-GF-Tic-Oic-G-Tic-G-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dab-Dab-Dab-Dab-CONH₂

(NH₂)₄-(Orn)₂-Orn-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-CONH₂

Thi-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂

Ac-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-RRRR-CONH₂

Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH₂

Ac-GF-Oic-Oic-GK-Oic-Oic-GF-Oic-Oic-GK-Oic-KKKK-CONH₂

Cys-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂

(NH₂)₄-(Dpr)₂-Dpr-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-CONH₂

$(\text{NH}_2)_4$ -(Dab)₂-Dab-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-CONH₂
 Ac-G-Nph-Tic-Oic-GK-Tic-Oic-G-Nph-Tic-Oic-GK-Tic-KKKK-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Gaba-KKKK-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Ahx-KKKK-CONH₂
 Ac-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Dab-Dab-Dab-Dab-CONH₂
 Thi-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂
 Ac-GF-Tic-Oic-GW-Tic-Oic-GF-Tic-Oic-GW-Tic-KKKK-CONH₂
 Ac-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-RRRR-CONH₂
 Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH₂
 Ac-G-Cph-Tic-Oic-GK-Tic-Oic-G-Cph-Tic-Oic-GK-Tic-KKKK-CONH₂
 Ac-GF-Oic-Tic-GK-Oic-Tic-GF-Oic-Tic-GK-Tic-KKKK-CONH₂
 Ac-βAla-Fpa-Tic-Oic-βAla-K-Tic-Oic-βAla-Fpa-Tic-Oic-βAla-K-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂,
 Ac-KKKK-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂
 $(\text{NH}_2)_4$ -(K)₂-K-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-CONH₂
 Ac-G-Fpa-Tic-Oic-G-Dpr-Tic-Oic-G-Fpa-Tic-Oic-G-Dpr-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Gaba-KKKK-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Ahx-KKKK-CONH₂
 Ac-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Dab-Dab-Dab-Dab-CONH₂
 Ac-GF-Tic-Oic-G-Tic-Oic-GF-Tic-Oic-G-Tic-G-KKKK-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dab-Dab-Dab-Dab-CONH₂
 $(\text{NH}_2)_4$ -(Orn)₂-Orn-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-CONH₂

Thi-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂

Ac-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-RRRR-CONH₂

Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH₂

Ac-GF-Oic-Oic-GK-Oic-Oic-GF-Oic-Oic-GK-Oic-KKKK-CONH₂,

Cys-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂,

(NH₂)₄-(Dpr)₂-Dpr-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-

CONH₂,

(NH₂)₄-(Dab)₂-Dab-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-

Tic-CONH₂,

Ac-KKKK-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-CONH₂.

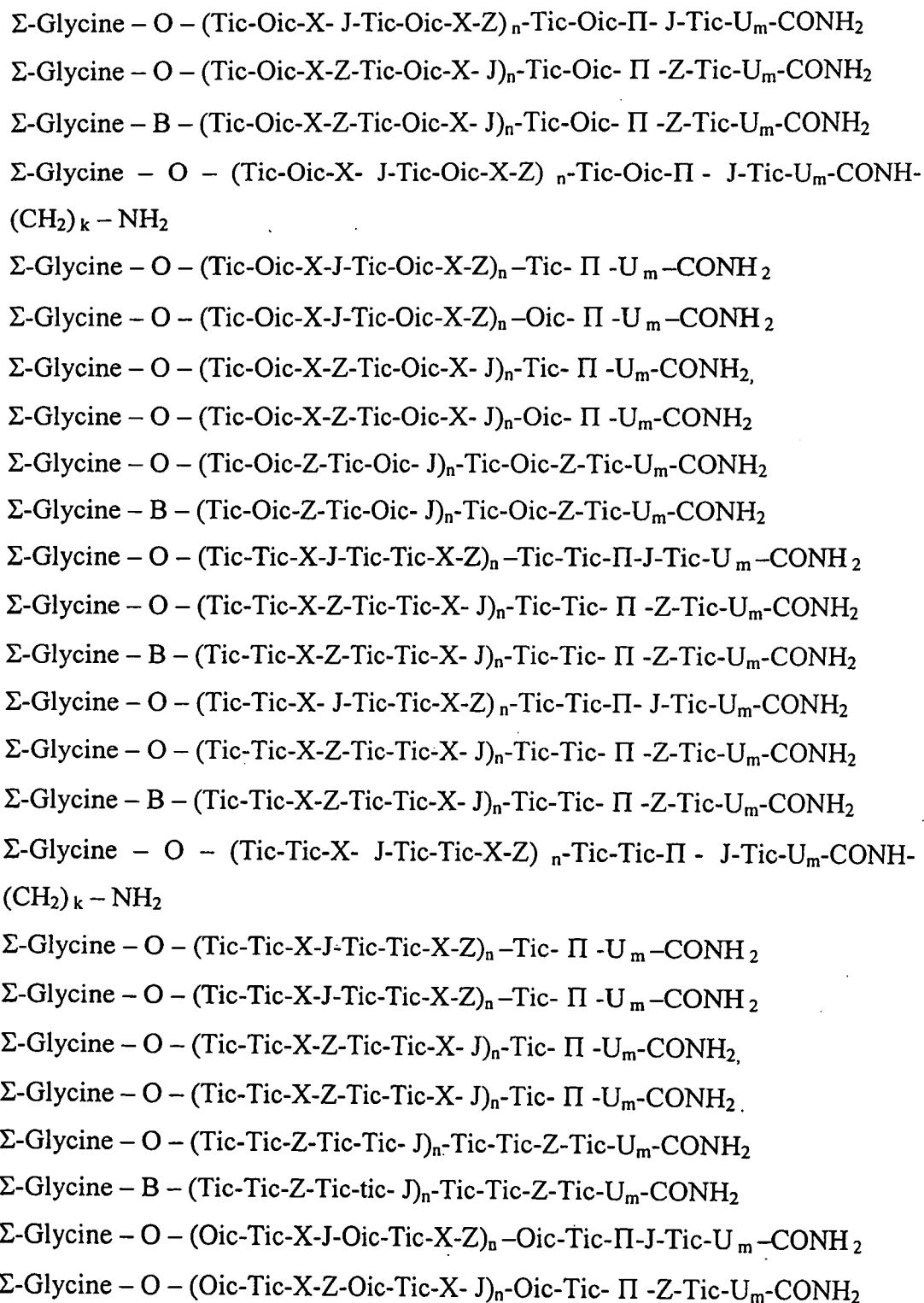
5. The antimicrobial peptide of claim 1, which is stably in association with a pharmaceutically acceptable adjuvant.

6. A method for treating at least one of Gram positive bacteria, Gram negative bacteria, Mycobacterium, Plasmodium falciparum, Candida albicans Cryptococcus neoformans, Botrytis cinerea, Fusarium culmorum or Neurospora crassa, comprising the step of administering to a mammal suspected of infection by at least one of Gram positive bacteria, Gram negative bacteria or Mycobacterium a pharmaceutically effective amount of at least one of the synthetic antimicrobial peptide analogs having a formula selected from the group consisting of:

$$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Oic-X-J-Tic-Oic-X-Z})_n - \text{Tic-Oic-}\Pi\text{-J-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Oic-X-Z-Tic-Oic-X-J})_n - \text{Tic-Oic-}\Pi\text{-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{B} - (\text{Tic-Oic-X-Z-Tic-Oic-X-J})_n - \text{Tic-Oic-}\Pi\text{-Z-Tic-U}_m\text{-CONH}_2$$



$$\Sigma\text{-Glycine} - \text{B} - (\text{Oic-Tic-X-Z-Oic-Tic-X- J})_n\text{-Oic-Tic- } \Pi \text{-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Tic-X- J-Oic-Tic-X-Z})_n\text{-Oic-Tic-}\Pi\text{- J-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Tic-X-Z-Oic-Tic-X- J})_n\text{-Oic-Tic- } \Pi \text{-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{B} - (\text{Oic-Tic-X-Z-Oic-Tic-X- J})_n\text{-Oic-Tic- } \Pi \text{-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Tic-X- J-Tic-Tic-X-Z})_n\text{-Tic-Tic-}\Pi \text{- J-Tic-U}_m\text{-CONH-} \\ (\text{CH}_2)_k - \text{NH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Tic-X-J-Oic-Tic-X-Z})_n\text{-Tic- } \Pi \text{-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Tic-X-J-Oic-Tic-X-Z})_n\text{-Tic- } \Pi \text{-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Tic-X-Z-Oic-Tic-X- J})_n\text{-Tic- } \Pi \text{-U}_m\text{-CONH}_2,$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Tic-X-Z-Oic-Tic-X- J})_n\text{-Tic- } \Pi \text{-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Tic-Z-Oic-Tic- J})_n\text{-Oic-Tic-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{B} - (\text{Oic-Tic-Z-Oic-tic- J})_n\text{-Oic-Tic-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-X-J-Oic-Oic-X-Z})_n\text{-Oic-Oic-}\Pi\text{-J-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-X-Z-Oic-Oic-X- J})_n\text{-Oic-Oic- } \Pi \text{-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{B} - (\text{Oic-Oic-X-Z-Oic-Oic-X- J})_n\text{-Oic-Oic- } \Pi \text{-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-X- J-Oic-Oic-X-Z})_n\text{-Oic-Oic-}\Pi\text{- J-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-X-Z-Oic-Oic-X- J})_n\text{-Oic-Oic- } \Pi \text{-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{B} - (\text{Oic-Oic-X-Z-Oic-Oic-X- J})_n\text{-Oic-Oic- } \Pi \text{-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-X- J-Oic-Oic-X-Z})_n\text{-Oic-Oic-}\Pi \text{- J-Tic-U}_m\text{-CONH-} \\ (\text{CH}_2)_k - \text{NH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-X-J-Oic-Oic-X-Z})_n\text{-Tic- } \Pi \text{-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-X-J-Oic-Oic-X-Z})_n\text{-Tic- } \Pi \text{-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-X-Z-Oic-Oic-X- J})_n\text{-Tic- } \Pi \text{-U}_m\text{-CONH}_2,$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-X-Z-Oic-Oic-X- J})_n\text{-Tic- } \Pi \text{-U}_m\text{-CONH}_2.$$

$$\Sigma\text{-Glycine} - \text{O} - (\text{Oic-Oic-Z-Oic-Oic- J})_n\text{-Oic-Oic-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-Glycine} - \text{B} - (\text{Oic-Oic-Z-Oic-tic- J})_n\text{-Oic-Oic-Z-Tic-U}_m\text{-CONH}_2$$

$$\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Oic-X-J-Tic-Oic-X-Z})_n\text{-Tic-Oic-}\Pi\text{-J-Tic-CONH}_2$$

$\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Oic-X-Z-Tic-Oic-X- J})_n\text{- Tic-Oic-}\Pi\text{-Z-Tic-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{B} - (\text{Tic-Oic-X-Z-Tic-Oic-X- J})_n\text{- Tic-Oic- } \Pi\text{-Z-Tic-CONH}_2$
 $\Sigma\text{-U}_m\text{ Glycine} - \text{O} - (\text{Tic-Oic-X- J-Tic-Oic-X-Z})_n\text{- Tic-Oic- } \Pi\text{- J-Tic-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Oic-X-Z-Tic-Oic-X- J})_n\text{- Tic-Oic- } \Pi\text{-Z-Tic-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{B} - (\text{Tic-Oic-X-Z-Tic-Oic-X- J})_n\text{- Tic-Oic- } \Pi\text{- Z-Tic-CONH}_2$,
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Oic-X- J-Tic-Oic-X-Z})_n\text{- Tic-Oic- } \Pi\text{- J-Tic-CONH-}$
 $(\text{CH}_2)_k - \text{NH}_2$

$\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Oic-X-J-Tic-Oic-X-Z})_n\text{-Tic- } \Pi\text{-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Oic-X-J-Tic-Oic-X-Z})_n\text{-Oic -}\Pi\text{-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Oic-X-Z-Tic-Oic-X- J})_n\text{-Tic- } \Pi\text{-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Oic-X-Z-Tic-Oic-X- J})_n\text{-Oic- } \Pi\text{-CONH}_2$

$\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-J-Tic-Tic-X-Z})_n\text{-Tic-Oic-}\Pi\text{-J-Tic-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-Z-Tic-Tic-X- J})_n\text{- Tic-Oic-}\Pi\text{-Z-Tic-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{B} - (\text{Tic-Tic-X-Z-Tic-Tic-X- J})_n\text{- Tic-Oic- } \Pi\text{-Z-Tic-CONH}_2$
 $\Sigma\text{-U}_m\text{ Glycine} - \text{O} - (\text{Tic-Tic-X- J-Tic-Tic-X-Z})_n\text{- Tic-Oic- } \Pi\text{- J-Tic-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-Z-Tic-Tic-X- J})_n\text{- Tic-Oic- } \Pi\text{-Z-Tic-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{B} - (\text{Tic-Tic-X-Z-Tic-Tic-X- J})_n\text{- Tic-Oic- } \Pi\text{- Z-Tic-CONH}_2$,
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Tic-X- J-Tic-Tic-X-Z})_n\text{- Tic-Oic- } \Pi\text{- J-Tic-CONH-}$
 $(\text{CH}_2)_k - \text{NH}_2$

$\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-J-Tic-Tic-X-Z})_n\text{-Tic- } \Pi\text{-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-J-Tic-Tic-X-Z})_n\text{-Oic -}\Pi\text{-CONH}_2$
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-Z-Tic-Tic-X- J})_n\text{-Tic- } \Pi\text{-CONH}_2$ and
 $\Sigma\text{-U}_m\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-Z-Tic-Tic-X- J})_n\text{-Oic- } \Pi\text{-CONH}_2$,

wherein Tic stands for tetrahydroisoquinolinecarboxylic acid,

Oic stands for octahydroindolecarboxylic acid,

Σ is acetyl, NH_2 , biotin, β -thienylalanine (Thi), cysteine, Keyhole Limpet Haemocyanin (KLH), or Bovine Serum Albumine (BSA).

U is lysine, arginine, histidine, ornithine, 2,3-diaminopropionic acid (Dpr), diaminobutanoic acid (Dab), 4-aminopiperidine-4-carboxylic acid (Apc4), or 3-aminopiperidine-3-carboxylic acid (Apc3),

X is glycine, alanine, β -alanine, gamma-aminobutyric acid (Gaba), ϵ -aminohexanoic acid (Ahx), phenylglycine (Phg), 9-aminooctanoic acid (9-Aoa), 10-aminodecanoic acid (10Ada), 12-aminododecanoic acid (12-Adda), or 16-aminopalmitic acid (16-Apa),

J is lysine, arginine, histidine, ornithine, 2,3-diaminopropionic acid (Dpr), or 2,4-diaminobutanoic acid (Dab),

Z is phenylalanine, tyrosine, tryptophan, 4-fluorophenylalanine (Fpa), 4-chlorophenylalanine (Cph), 4-nitrophenylalanine (Nph), phenyl glycine (Phg), valine, isoleucine, norvaline, norleucine, norisoleucine, 4-Aminobutyric acid, piperidinic acid, 6-Aminocaproic acid, 2-Aminoheptanoic acid, 2-Aminoisobutyric acid, 3-Aminoisobutyric acid, 2-Aminopimelic acid, 2,4-Diaminobutyric acid, N-Ethylglycine, allo-Isoleucine, N-Methylglycine, N-Methylisoleucine, or N-Methylvaline,

O is phenylalanine, leucine, valine or isoleucine,

B is lysine, arginine, histidine, ornithine, 2,3-diaminopropionic acid (Dpr), 2,4-diaminobutanoic acid (Dab), 4-aminopiperidine-4-carboxylic acid (Apc4), or 3-aminopiperidine-3-carboxylic acid (Apc3),

Π is glycine, alanine, β -alanine, gamma-aminobutyric acid (Gaba), or ϵ -Aminohexanoic acid (Ahx),

n is 1 to 4 repeating units,

m is 1 to 5 repeating units, and

k is 1 to 5 repeating units,

and a pharmaceutically acceptable adjuvant.

7. The method of claim 6 wherein the antimicrobial peptide in its secondary structure includes at least three β -turns and exhibits sufficient conformational flexibility to bind to the membrane of at least one of Gram positive bacteria, Gram negative bacteria or Mycobacterium.

8. The method of claim 6, wherein the antimicrobial peptide exhibits less hemolytic activity than naturally occurring non-selective antimicrobial peptides.

9. The method of claim 6, wherein the at least one antimicrobial peptide is selected from the group consisting of

NH₂-GKGL-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GKR-

CONH₂

NH₂-GKGL-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-Oic-GKR-

CONH₂

NH₂-GKGL-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GLR-

CONH₂

NH₂-GKGL-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GK-Tic-Oic-GL-Tic-Oic-GLR-

CONH₂

NH₂-GKGL-Tic-Oic-FK-Tic-Oic-KF-Tic-Oic-FK-Tic-Oic-KF-Tic-Oic-FK-Tic-Oic-FKR-

CONH₂

NH₂-KL-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-Oic-KR-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK- CONH-CH₂-CH₂-NH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH-CH₂-CH₂-CH₂-NH₂

NH₂--GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂
 NH₂--KL-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂
 Ac-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-KKKK-CONH₂
 Ac-Gaba-F-Tic-Oic-Gaba-K-Tic-Oic-Gaba-F-Tic-Oic-Gaba-K-Tic-KKKK-CONH₂
 Ac-G-Tic-Oic-K-Tic-Oic-G-Tic-Oic-K-Tic-KKKK-CONH₂
 Ac-GF-Oic-GK-Oic-GF-Oic-GKKKKK-CONH₂
 Ac-GF-Tic-GK-Tic-GF-Tic-GK-Tic-KKKK-CONH₂
 Ac-GF-Tic-G-GK-Tic-G-GF-Tic-G-GK-Tic-KKKK-CONH₂
 Ac-GF-G-Oic-GK-G-Oic-GF-G-Oic-GK-G-KKKK-CONH₂
 Ac-GF-F-Oic-GK-F-Oic-GF-F-Oic-GK-F-KKKK-CONH₂
 Ac-βAla-F-Tic-Oic-βAla-K-Tic-Oic-βAla-F-Tic-Oic-βAla-K-Tic-KKKK-CONH₂
 Ac-Ahx-F-Tic-Oic-Ahx-K-Tic-Oic-Ahx-F-Tic-Oic-Ahx-K-Tic-KKKK-CONH₂
 Ac-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-KKKKKK-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKKKK-CONH₂
 Ac-Gaba-F-Tic-Oic-Gaba-K-Tic-Oic-Gaba-F-Tic-Oic-Gaba-K-Tic-KKKKKK-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Orn-Orn-Orn-Orn-CONH₂
 Ac-G-Fpa-Tic-Oic-GK-Tic-Oic-G-Fpa-Tic-Oic-GK-Tic-KKKK-CONH₂
 Ac-GF-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-Orn-Orn-Orn-CONH₂
 Biotin-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂
 Ac-GF-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-Dpr-DprDpr-Dpr-CONH₂
 Ac-βAla-Fpa-Tic-Oic-βAla-Dpr-Tic-Oic-βAla-Fpa-Tic-Oic-βAla-Dpr-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂
 Ac-G-dF-Tic-Oic-GK-Tic-Oic-G dF-Tic-Oic-GK-Tic-KKKK-CONH₂
 Ac-GF-Tic-Oic-G-dK-Tic-Oic-GF-Tic-Oic-G-dK-Tic-KKKK-CONH₂
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂
 (NH₂)₄ -(K)₂-K-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-CONH₂

Ac-G-Fpa-Tic-Oic-G-Dpr-Tic-Oic-G-Fpa -Tic-Oic-G-Dpr-Tic-Dpr-Dpr-Dpr-Dpr-
CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-βA-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Gaba-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Ahx-KKKK-CONH₂

Ac-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Dab-Dab-Dab-Dab-CONH₂

Ac-GF-Tic-Oic-G-Tic-Oic-GF-Tic-Oic-G-Tic-G-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dab-Dab-Dab-Dab-CONH₂

(NH₂)₄-(Orn)₂-Orn-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-
Orn-Tic-

CONH₂

Thi-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂

Ac-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-RRRR-CONH₂

Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH₂

Ac-GF-Oic-Oic-GK-Oic-Oic-GF-Oic-Oic-GK-Oic-KKKK-CONH₂

Cys-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂

(NH₂)₄-(Dpr)₂-Dpr-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-
Dpr-Tic-

CONH₂

(NH₂)₄-(Dab)₂-Dab-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-
Dab-Tic-CONH₂

Ac-G-Nph-Tic-Oic-GK-Tic-Oic-G-Nph-Tic-Oic-GK-Tic-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Gaba-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Ahx-KKKK-CONH₂

Ac-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Dab-Dab-Dab-Dab-CONH₂

Thi-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂

Ac-GF-Tic-Oic-GW-Tic-Oic-GF-Tic-Oic-GW-Tic-KKKK-CONH₂

Ac-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-RRRR-CONH₂

Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH₂

Ac-G-Cph-Tic-Oic-GK-Tic-Oic-G-Cph-Tic-Oic-GK-Tic-KKKK-CONH₂

Ac-GF-Oic-Tic-GK-Oic-Tic-GF-Oic-Tic-GK-Tic-KKKK-CONH₂

Ac-βAla-Fph-Tic-Oic-βAla-K-Tic-Oic-βAla-Fph-Tic-Oic-βAla-K-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂,

Ac-KKKK-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂

(NH₂)₄ - (K)₂-K-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-CONH₂

Ac-G-Fpa-Tic-Oic-G-Dpr-Tic-Oic-G-Fpa - Tic-Oic-G-Dpr-Tic-Dpr-Dpr-Dpr-Dpr-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Gaba-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Ahx-KKKK-CONH₂

Ac-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Dab-Dab-Dab-Dab-CONH₂

Ac-GF-Tic-Oic-G-Tic-Oic-GF-Tic-Oic-G-Tic-G-KKKK-CONH₂

Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Dab-Dab-Dab-Dab-CONH₂

(NH₂)₄-(Orn)₂-Orn-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-

CONH₂

Thi-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂

Ac-GF-Tic-Oic-GR-Tic-Oic-GF-Tic-Oic-GR-Tic-RRRR-CONH₂

Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH₂

Ac-GF-Oic-Oic-GK-Oic-Oic-GF-Oic-Oic-GK-Oic-KKKK-CONH₂,

Cys-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-G-KKKK-CONH₂,

(NH₂)₄-(Dpr)₂-Dpr-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-Oic-GF-Tic-Oic-G-Dpr-Tic-

CONH₂,

$(\text{NH}_2)_4\text{-(Dab)}_2\text{-Dab-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-}$

Tic-CONH_2 and

$\text{Ac-KKKK-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-CONH}_2$.

10. The method of claim 6 wherein the antimicrobial peptide is administered by topical, intravenous, infusion, and oral administration.

11. The method of claim 6, wherein the synthetic antimicrobial peptide analog is administered in conjunction with an antibiotic.

12. The method of claim 6, wherein the antibiotic is selected from the group consisting of ciprofloxacin, carbenicillin, nalidixic acid, amoxicillin, levofloxacin, cefuroxime and erythromycin, imipenem, rifampicin and azithromycin.

13. The method of claim 6, wherein the infection is by *Mycobacterium*, and the at least one synthetic antimicrobial peptide analog has the formula selected from the group consisting of

$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-J-Tic-Tic-X-Z})_n - \text{Tic-Tic-}\Pi\text{-J-Tic-U}_m - \text{CONH}_2$

$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-Z-Tic-Tic-X-J})_n - \text{Tic-Tic-}\Pi\text{-Z-Tic-U}_m - \text{CONH}_2$

$\Sigma\text{-Glycine} - \text{B} - (\text{Tic-Tic-X-Z-Tic-Tic-X-J})_n - \text{Tic-Tic-}\Pi\text{-Z-Tic-U}_m - \text{CONH}_2$

$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-J-Tic-Tic-X-Z})_n - \text{Tic-Tic-}\Pi\text{-J-Tic-U}_m - \text{CONH}_2$

$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-Z-Tic-Tic-X-J})_n - \text{Tic-Tic-}\Pi\text{-Z-Tic-U}_m - \text{CONH}_2$

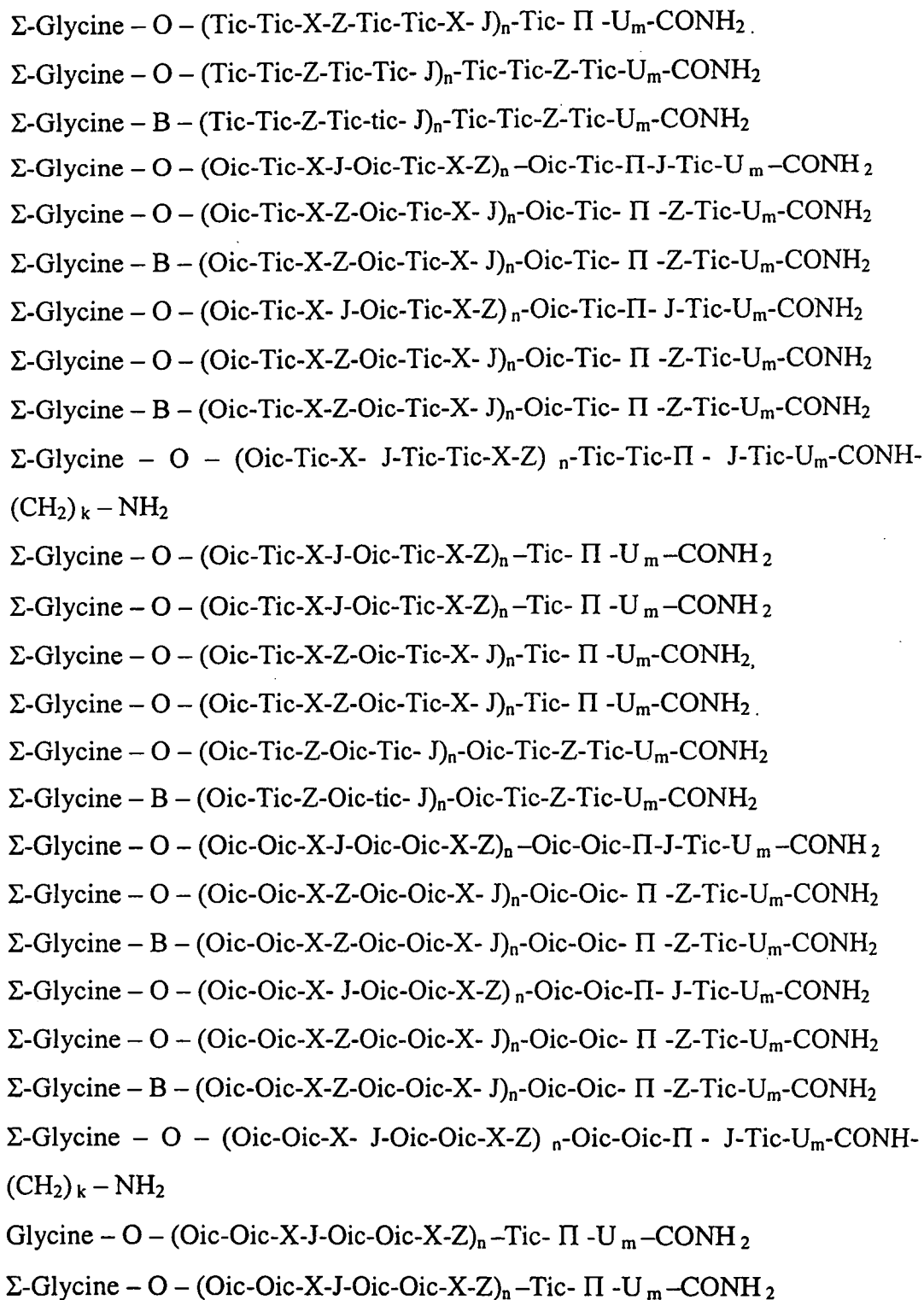
$\Sigma\text{-Glycine} - \text{B} - (\text{Tic-Tic-X-Z-Tic-Tic-X-J})_n - \text{Tic-Tic-}\Pi\text{-Z-Tic-U}_m - \text{CONH}_2$

$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-J-Tic-Tic-X-Z})_n - \text{Tic-Tic-}\Pi\text{-J-Tic-U}_m - \text{CONH} - (\text{CH}_2)_k - \text{NH}_2$

$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-J-Tic-Tic-X-Z})_n - \text{Tic-}\Pi\text{-U}_m - \text{CONH}_2$

$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-J-Tic-Tic-X-Z})_n - \text{Tic-}\Pi\text{-U}_m - \text{CONH}_2$

$\Sigma\text{-Glycine} - \text{O} - (\text{Tic-Tic-X-Z-Tic-Tic-X-J})_n - \text{Tic-}\Pi\text{-U}_m - \text{CONH}_2$,



Σ -Glycine – O – (Oic-Oic-X-Z-Oic-Oic-X- J)_n-Tic- Π -U_m-CONH₂,
 Σ -Glycine – O – (Oic-Oic-X-Z-Oic-Oic-X- J)_n-Tic- Π -U_m-CONH₂.
 Σ -Glycine – O – (Oic-Oic-Z-Oic-Oic- J)_n-Oic-Oic-Z-Tic-U_m-CONH₂
 Σ -Glycine – B – (Oic-Oic-Z-Oic-tic- J)_n-Oic-Oic-Z-Tic-U_m-CONH₂
 Σ -U_m-Glycine – O – (Tic-Tic-X-J-Tic-Tic-X-Z)_n-Tic-Oic-Π-J-Tic –CONH₂
 Σ -U_m-Glycine – O – (Tic-Tic-X-Z-Tic-Tic-X- J)_n- Tic-Oic-Π-Z-Tic-CONH₂
 Σ -U_m-Glycine – B – (Tic-Tic-X-Z-Tic-Tic-X- J)_n- Tic-Oic- Π -Z-Tic-CONH₂
 Σ -U_m Glycine – O – (Tic-Tic-X- J-Tic-Tic-X-Z)_n- Tic-Oic- Π - J-Tic-CONH₂
 Σ -U_m -Glycine – O – (Tic-Tic-X-Z-Tic-Tic-X- J)_n- Tic-Oic- Π -Z-Tic-CONH₂
 Σ -U_m -Glycine – B – (Tic-Tic-X-Z-Tic-Tic-X- J)_n- Tic-Oic- Π- Z-Tic-CONH₂ ,
 Σ -U_m-Glycine – O – (Tic-Tic-X- J-Tic-Tic-X-Z)_n- Tic-Oic- Π - J-Tic-CONH-
(CH₂)_k – NH₂
 Σ -U_m-Glycine – O – (Tic-Tic-X-J-Tic-Tic-X-Z)_n-Tic- Π –CONH₂
 Σ -U_m-Glycine – O – (Tic-Tic-X-J-Tic-Tic-X-Z)_n-Oic -Π –CONH₂ .
 Σ -U_m-Glycine – O – (Tic-Tic-X-Z-Tic-Tic-X- J)_n-Tic- Π -CONH₂ and
 Σ -U_m-Glycine – O – (Tic-Tic-X-Z-Tic-Tic-X- J)_n-Oic- Π -CONH₂.

14. The method of claim 13, wherein the at least one synthetic antimicrobial peptide is Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH₂ or Ac-GF-Oic-Tic-GK-Oic-Tic-GF-Oic-Tic-GK-Tic-KKKK-CONH₂ or Ac-KKKK-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-CONH₂, or a combination of these.

15. A method for treating infection by *Bacillus anthracis* or *Yersinia pestis* (plague), comprising the step of administering to a mammal suspected of infection by *Bacillus anthracis* or *Yersinia pestis* (plague), a pharmaceutically effective amount of one of the

synthetic antimicrobial peptides NH₂-KL-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-Oic-F-Tic-Oic-K-Tic-Oic-KR-CONH₂,
 Ac-GF-Tic-GK-Tic-GF-Tic-GK-Tic-KKKK-CONH₂,
 Ac-βAla-F-Tic-Oic-βAla-K-Tic-Oic-βAla-F-Tic-Oic-βAla-K-Tic-KKKK-CONH₂,
 Ac-G-Fpa-Tic-Oic-GK-Tic-Oic-G-Fpa-Tic-Oic-GK-Tic-KKKK-CONH₂,
 Ac-GF-Tic-Oic-G-Orn-Tic-Oic-GF-Tic-Oic-G-Orn-Tic-Orn-Orn-Orn-Orn-CONH₂,
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-βA-KKKK-CONH₂,
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Gaba-KKKK-CONH₂,
 Ac-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-Ahx-KKKK-CONH₂,
 Ac-GF-Tic-Oic-G-Dab-Tic-Oic-GF-Tic-Oic-G-Dab-Tic-Dab-Dab-Dab-Dab-CONH₂,
 Thi-GF-Tic-Oic-GK-Tic-Oic-GF-Tic-Oic-GK-Tic-KKKK-CONH₂,
 Ac-GF-Tic-Oic-GW-Tic-Oic-GF-Tic-Oic-GW-Tic-KKKK-CONH₂,
 Ac-GF-Tic-Tic-GK-Tic-Tic-GF-Tic-Tic-GK-Tic-KKKK-CONH₂,
 Ac-G-Cph-Tic-Oic-GK-Tic-Oic-G-Cph-Tic-Oic-GK-Tic-KKKK-CONH₂,
 or a combination of these.

16. The method of claim 15, wherein the antimicrobial peptide exhibits less hemolytic activity than naturally occurring non-selective antimicrobial peptides.

17. A synthetic peptide with bioactivity against *Staphylococcus aureus* (SA) satisfying at least four terms of the mathematical equation: SA predicted bioactivity = $[(-1.4959 \times \text{"Fcharge"}) + (0.0098 \times \text{"dipole-mag"}) + (0.0140 \times \text{"Jurs-SASA"}) + (0.0023 \times \text{"Jurs-PPSA-1"}) + (0.1876 \times \text{"Jurs-PNSA-1"}) + (0.0022 \times \text{"Jurs-PNSA-2"}) + (0.00037 \times \text{"Jurs-DPSA-2"}) + (0.0015 \times \text{"Jurs-DPSA-3"}) + (438.251 \times \text{"Jurs-FPSA-1"}) + (267.258 \times \text{"Jurs-FPSA-3"}) + (120.432 \times \text{"Jurs-FNSA-3"}) - (715.316 \times \text{"Jurs-RPCG"}) - (12.8649 \times \text{"Jurs-RPCS"}) - (0.0658 \times \text{"Jurs-TASA"}) - (125.513 \times \text{"Jurs-RPSA"}) + (125.513 \times \text{"Jurs-RASA"}) - (183.99 \times \text{"density"}) + (1.0340 \times \text{"Hbond acceptor"}) + (0.0395 \times \text{"Hbond donor"}) - (0.3069 \times \text{"Rotlbonds"}) + (0.1148 \times \text{"AlogP"}) - (0.10004 \times \text{"RadOfGyration"}) - 225.589]$.

18. The synthetic peptide with bioactivity against *Staphylococcus aureus* (SA) according to claim 17, satisfying the mathematical equation: SA predicted bioactivity = $[(-1.49592 \times \text{"Fcharge"}) + (0.0098147 \times \text{"dipole-mag"}) + (0.013993 \times \text{"Jurs-SASA"}) + (0.00233 \times \text{"Jurs-PPSA-1"}) + (0.187647 \times \text{"Jurs-PNSA-1"}) + (0.0021686 \times \text{"Jurs-PNSA-2"}) + (0.00036919 \times \text{"Jurs-DPSA-2"}) + (0.0015025 \times \text{"Jurs-DPSA-3"}) + (438.251 \times \text{"Jurs-FPSA-1"}) + (267.258 \times \text{"Jurs-FPSA-3"}) + (120.432 \times \text{"Jurs-FNSA-3"}) - (715.316 \times \text{"Jurs-RPCG"}) - 12.8649 \times \text{"Jurs-RPCS"}) - (0.065752 \times \text{"Jurs-TASA"}) - (125.513 \times \text{"Jurs-RPSA"}) + (125.513 \times \text{"Jurs-RASA"}) - (183.99 \times \text{"density"}) + (1.03397 \times \text{"Hbond acceptor"}) + (0.039473 \times \text{"Hbond donor"}) - (0.306856 \times \text{"Rotlbonds"}) + (0.114808 \times \text{"AlogP"}) - (0.10004 \times \text{"RadOfGyration"}) - 225.589.$

19. The synthetic peptide with bioactivity against *Staphylococcus aureus* (SA) according to claim 17, having at least four of the following physicochemical properties, wherein the respective percentages of each property indicate the relative contribution toward the bioactivity: Jurs-FPSA-1 – 29.347%; density – 16.010%; Jurs-TASA – 14.762%; Jurs-PNSA-1 – 10.540%; Jurs-RASA – 7.886%; Jurs-SASA – 4.120%; Jurs-DPSA-2 – 3.093%; Jurs-PNSA-2 – 2.911%; Jurs-RPSA – 2.492%; Rotlbonds – 2.164%; Hbond acceptor – 1.910%; Jurs-FPSA-3 – 1.709%; Fcharge – 0.742%; Jurs-RPCG – 0.726%; Jurs-PPSA-1 – 0.555%; Jurs-FNSA-3 – 0.426%; Dipole-mag – 0.162%; RadOfGyration – 0.127%; Jurs-RPCS – 0.126%; Hbond donor – 0.113%; Jurs-DPSA-3 – 0.053%; and AlogP – 0.026%.

20. A synthetic peptide with bioactivity against *Mycobacterium ranae* (MR) satisfying at least four terms of the mathematical equation: MR predicted activity = $[(-0.0084 \times \text{"conformer energy"}) + (2.0576 \times \text{"Fcharge"}) + (0.00005 \times \text{"Apol"}) + (0.0061 \times \text{"dipole-mag"}) - (0.0239 \times \text{"Jurs-PPSA-1"}) - (0.0083 \times \text{"Jurs-PNSA-1"}) + (0.00005 \times \text{"Jurs-PPSA-2"}) + (0.00019 \times \text{"Jurs-PNSA-2"}) - (18.282 \times \text{"Jurs-FPSA-1"}) + (13.321 \times$

"Jurs-FNSA-3") - (8.4684 × "Jurs-RPCG") + (66.6262 × "Jurs-RNCG") + (0.0529 × "Jurs-TPSA") - (96.9761 × "Jurs-RPSA") + (96.9761 × "Jurs-RASA") - (127.577 × "density") + (0.7687 × "Hbond acceptor") - (0.4983 × "Hbond donor") - (0.0608 × "Rotlbonds") - (0.0758 × "AlogP") + (0.3378 × "RadOfGyration") + 110.841].

21. A synthetic peptide with bioactivity against *Mycobacterium ranae* (MR) according to claim 20, satisfying the mathematical equation: MR predicted activity = [(-0.0083585 × "conformer energy") + (2.05758 × "Fcharge") + (5.3259e-05 × "Apol") + (0.0061422 × "dipole-mag") - (0.023941 × "Jurs-PPSA-1") - (0.008252 × "Jurs-PNSA-1") + (5.5381e-05 × "Jurs-PPSA-2") + (0.00018566 × "Jurs-PNSA-2") - (18.282 × "Jurs-FPSA-1") + (13.321 × "Jurs-FNSA-3") - (8.46841 × "Jurs-RPCG") + (66.6262 × "Jurs-RNCG") + (0.052889 × "Jurs-TPSA") - (96.9761 × "Jurs-RPSA") + (96.9761 × "Jurs-RASA") - (127.577 × "density") + (0.768698 × "Hbond acceptor") - (0.498282 × "Hbond donor") - (0.060764 × "Rotlbonds") - (0.075759 × "AlogP") + (0.337835 × "RadOfGyration") + 110.841].

22. A synthetic peptide with bioactivity against *Mycobacterium ranae* (MR) according to claim 20, having at least four of the following physicochemical properties, wherein the respective percentages of each property indicate the relative contribution toward the bioactivity: Density – 30.784%; Jurs-RASA – 16.827%; Jurs-PPSA-1 – 15.494%; Jurs-TPSA – 10.218%; Jurs-RPSA – 5.444%; Hbond donor – 3.905%; Hbond acceptor – 3.729%; Jurs-FPSA-1 – 3.409%; Fcharge – 2.892%; Jurs-PNSA-1 – 1.244%; RadOfGyration – 1.164%; Rotlbonds – 1.156%; Apol – 1.148%; Jurs-PPSA-2 – 1.016%; Jurs-PNSA-2 – 0.632%; Jurs-RNCG – 0.400%; Dipole-mag – 0.298%; Jurs-FNSA-3 – 0.127%; AlogP – 0.051%; Conformer Energy – 0.037%; Jurs-RPCG – 0.024%; and Jurs-DPSA-2 – 0.00%.

23. A method for determining whether a synthetic peptide is bioactive against *Staphylococcus aureus* (SA), comprising the steps of:

i) determining the shape of a peptide that has minimum potential energy of the peptide;

ii) computing the conformational model for the peptide using standard Monte Carlo or molecular dynamics conformational search algorithms, so as to generate a pool of peptide conformations that are within 20Kcals/mol energy range of the global minimum conformation;

iii) selecting from the peptide conformations of step ii) the conformation having the maximum measurement of its backbone when measured from head to tail, which conformation is within five Kcals/mole energy range of the global minimum conformer;

iv) aligning all conformations of step ii) with the selected conformation of step iii), wherein the selected conformation is used as a template structure;

v) determining the physicochemical properties for all the aligned conformations, wherein the physicochemical properties determined are conformer energy, Fcharge, dipole-mag, Jurs-SASA, Jurs-PPSA-1, Jurs-PNSA-1, Jurs-PNSA-2, Jurs-DPSA-2, Jurs-DPSA-3, Jurs-FPSA-1, Jurs-FPSA-3, Jurs-FNSA-3, Jurs-RPCG, Jurs-RPCS, Jurs-TASA, Jurs-RPSA, Jurs-RASA, density, Hbond acceptor, Hbond donor, Rotlbonds, AlogP, and RadOfGyration; and

vi) applying a mathematical equation to each aligned conformation peptide, to *Staphylococcus aureus* (SA), which mathematical equation is: SA bioactivity equals satisfaction of at least four of the following terms: $(-1.49592 \times \text{"Fcharge"}) + (0.0098147 \times \text{"dipole-mag"}) + (0.013993 \times \text{"Jurs-SASA"}) + (0.00233 \times \text{"Jurs-PPSA-1"}) + (0.187647 \times \text{"Jurs-PNSA-1"}) + (0.0021686 \times \text{"Jurs-PNSA-2"}) + (0.00036919 \times \text{"Jurs-DPSA-2"}) + (0.0015025 \times \text{"Jurs-DPSA-3"}) + (438.251 \times \text{"Jurs-FPSA-1"}) + (267.258 \times \text{"Jurs-FPSA-3"}) + (120.432 \times \text{"Jurs-FNSA-3"}) - (715.316 \times \text{"Jurs-RPCG"}) - 12.8649 \times \text{"Jurs-RPCS"}) - (0.065752 \times \text{"Jurs-TASA"}) - (125.513 \times \text{"Jurs-RPSA"}) + (125.513 \times \text{"Jurs-RASA"}) - (183.99 \times \text{"density"}) + (1.03397 \times \text{"Hbond acceptor"}) + (0.039473 \times \text{"Hbond donor"}) -$

$$(0.306856 \times \text{"Rotlbonds"}) + (0.114808 \times \text{"AlogP"}) - (0.10004 \times \text{"RadOfGyration"}) - 225.589.$$

24. A method for determining whether a synthetic peptide is bioactive against *Mycobacterium ranae* (MR), comprising the steps of:

i) determining the shape of a peptide that has minimum potential energy of the peptide;

ii) computing the conformational model for the peptide using standard Monte Carlo or molecular dynamics conformational search algorithms, so as to generate a pool of peptide conformations that are within 20Kcals/mol energy range of the global minimum conformation;

iii) selecting from the peptide conformations of step ii) the conformation having the maximum measurement of its backbone when measured from head to tail, which conformation is within five Kcals/mole energy range of the global minimum conformer;

iv) aligning all conformations of step ii) with the selected conformation of step iii), wherein the selected conformation is used as a template structure;

v) determining the physicochemical properties for all the aligned conformations, wherein the physicochemical properties determined are conformer energy, Fcharge, Apol, dipole-mag, Jurs-PPSA-1, Jurs-PNSA-1, Jurs-PPSA-2, Jurs-PNSA-2, Jurs-FPSA-1, Jurs-FNSA-3, Jurs-RPCG, Jurs-RNCG, Jurs-TPSA, Jurs-RPSA, Jurs-RASA, density, Hbond acceptor, Hbond donor, Rotlbonds, AlogP, and RadOfGyration; and

vi) applying a mathematical equation to each aligned conformation peptide, to determine whether the synthetic peptide is bioactive against *Mycobacterium ranae* (MR), which mathematical equation is: MR bioactivity equals satisfaction of at least four of the following terms: $[(-0.0083585 \times \text{"conformer energy"}) + (2.05758 \times \text{"Fcharge"}) + (5.3259e-05 \times \text{"Apol"}) + (0.0061422 \times \text{"dipole-mag"}) - (0.023941 \times \text{"Jurs-PPSA-1"}) - (0.008252 \times \text{"Jurs-PNSA-1"}) + (5.5381e-05 \times \text{"Jurs-PPSA-2"}) + (0.00018566 \times \text{"Jurs-PNSA-2"}) - (18.282 \times \text{"Jurs-FPSA-1"}) + (13.321 \times \text{"Jurs-FNSA-3"}) - (8.46841 \times \text{"Jurs-PPSA-3"})]$

$$\begin{aligned} & \text{RPCG}) + (66.6262 \times \text{"Jurs-RNCG"}) + (0.052889 \times \text{"Jurs-TPSA"}) - (96.9761 \times \text{"Jurs-} \\ & \text{RPSA"}) + (96.9761 \times \text{"Jurs-RASA"}) - (127.577 \times \text{"density"}). + (0.768698 \times \text{"Hbond} \\ & \text{acceptor"}) - (0.498282 \times \text{"Hbond donor"}) - (0.060764 \times \text{"Rotlbonds"}) - (0.075759 \times \\ & \text{"AlogP"}) + (0.337835 \times \text{"RadOfGyration"}) + 110.841]. \end{aligned}$$

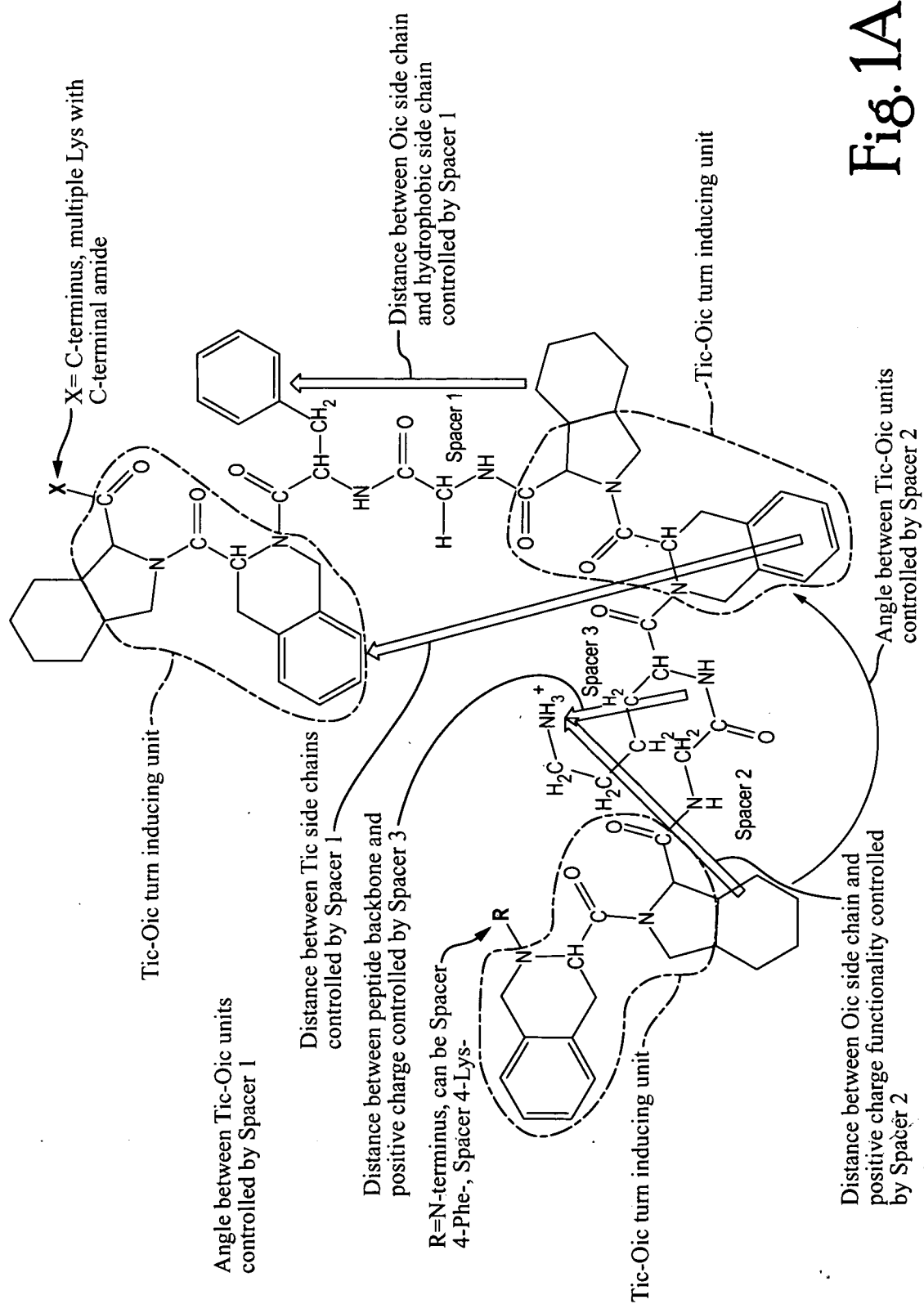


Fig. 1A

2/22

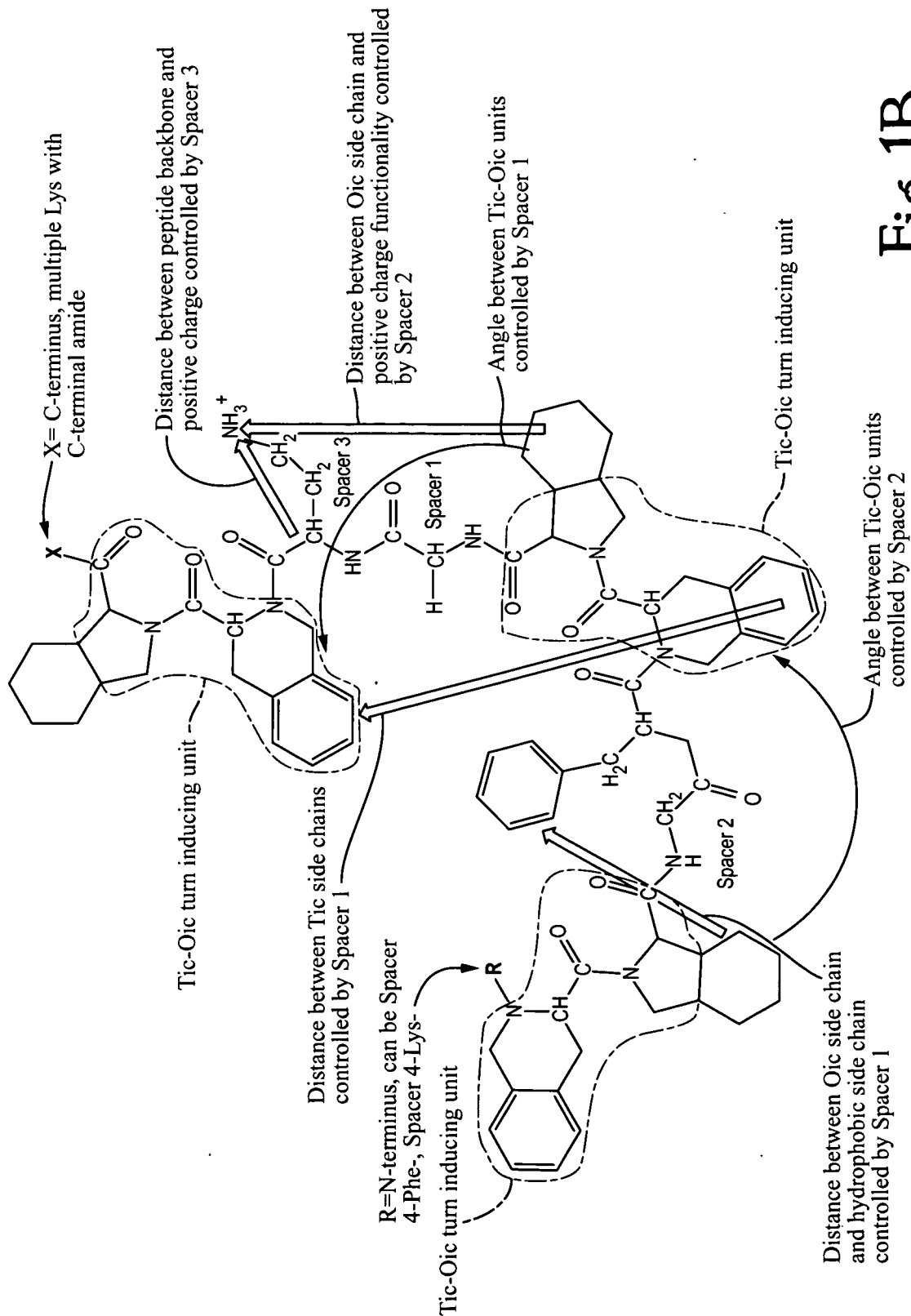


Fig. 1B

3/22

Fig. 2A

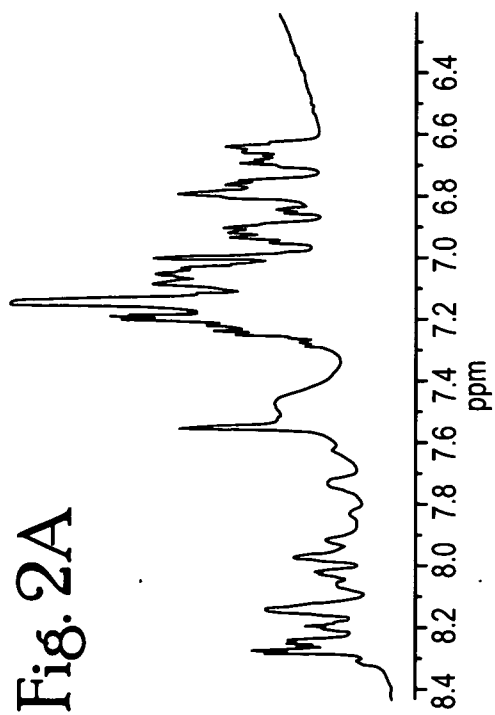


Fig. 2B

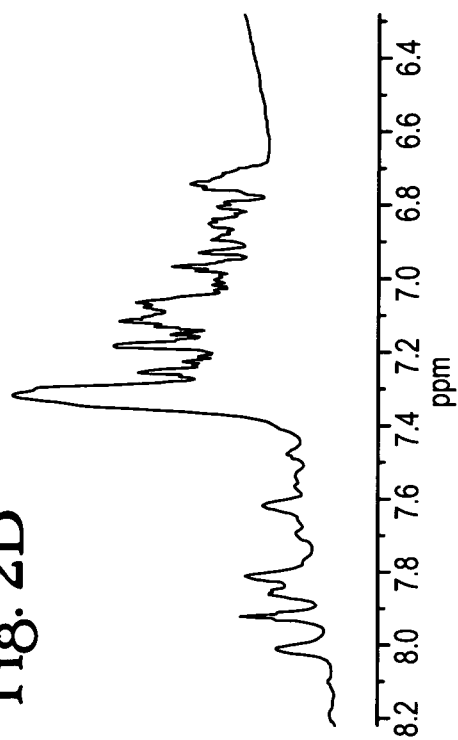


Fig. 2C

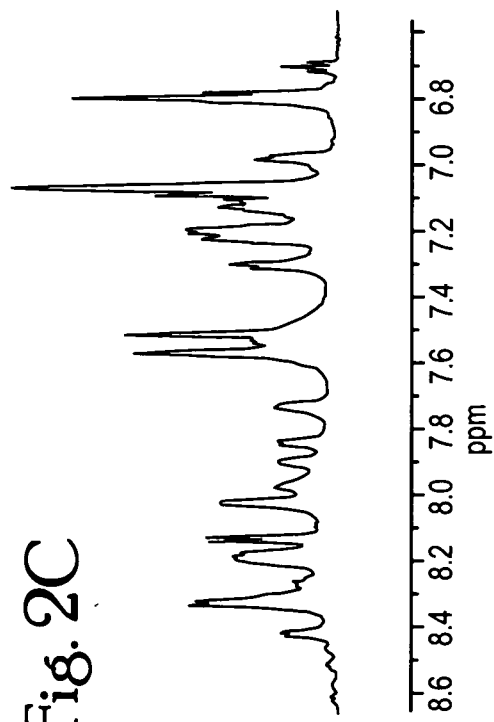
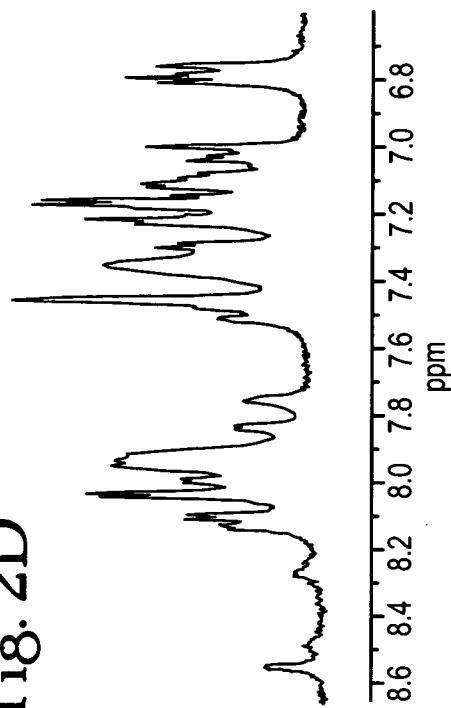
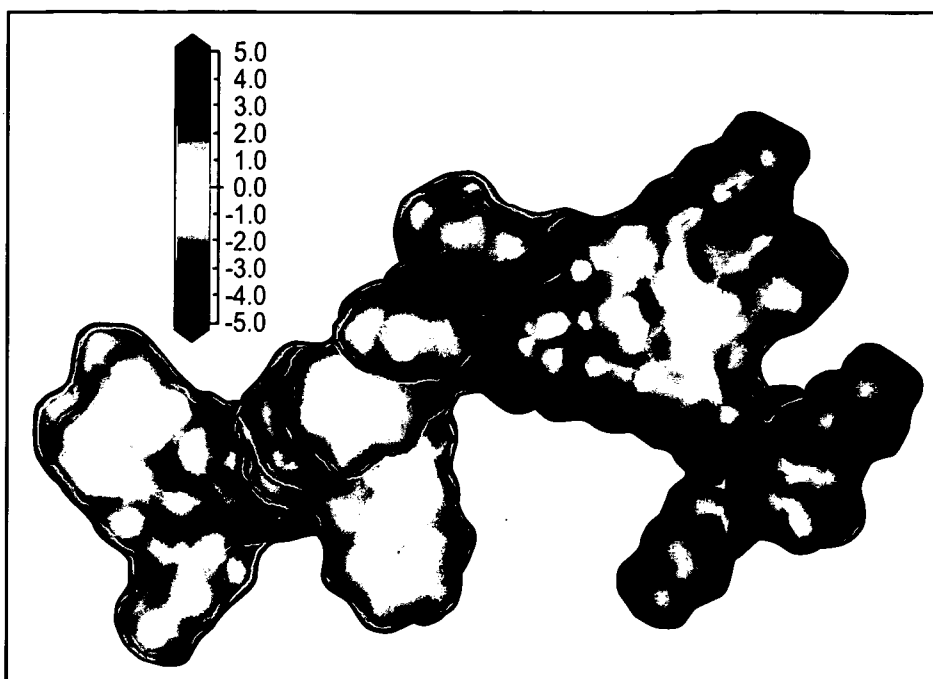


Fig. 2D

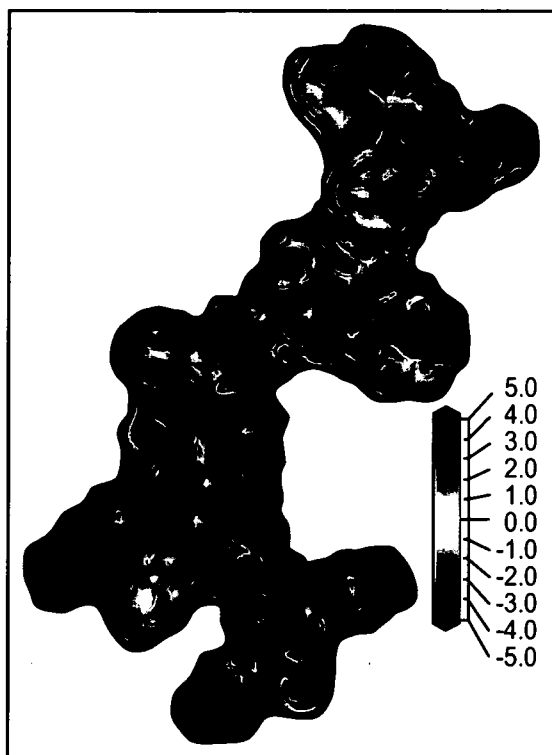


4/22



Non-Polar Face

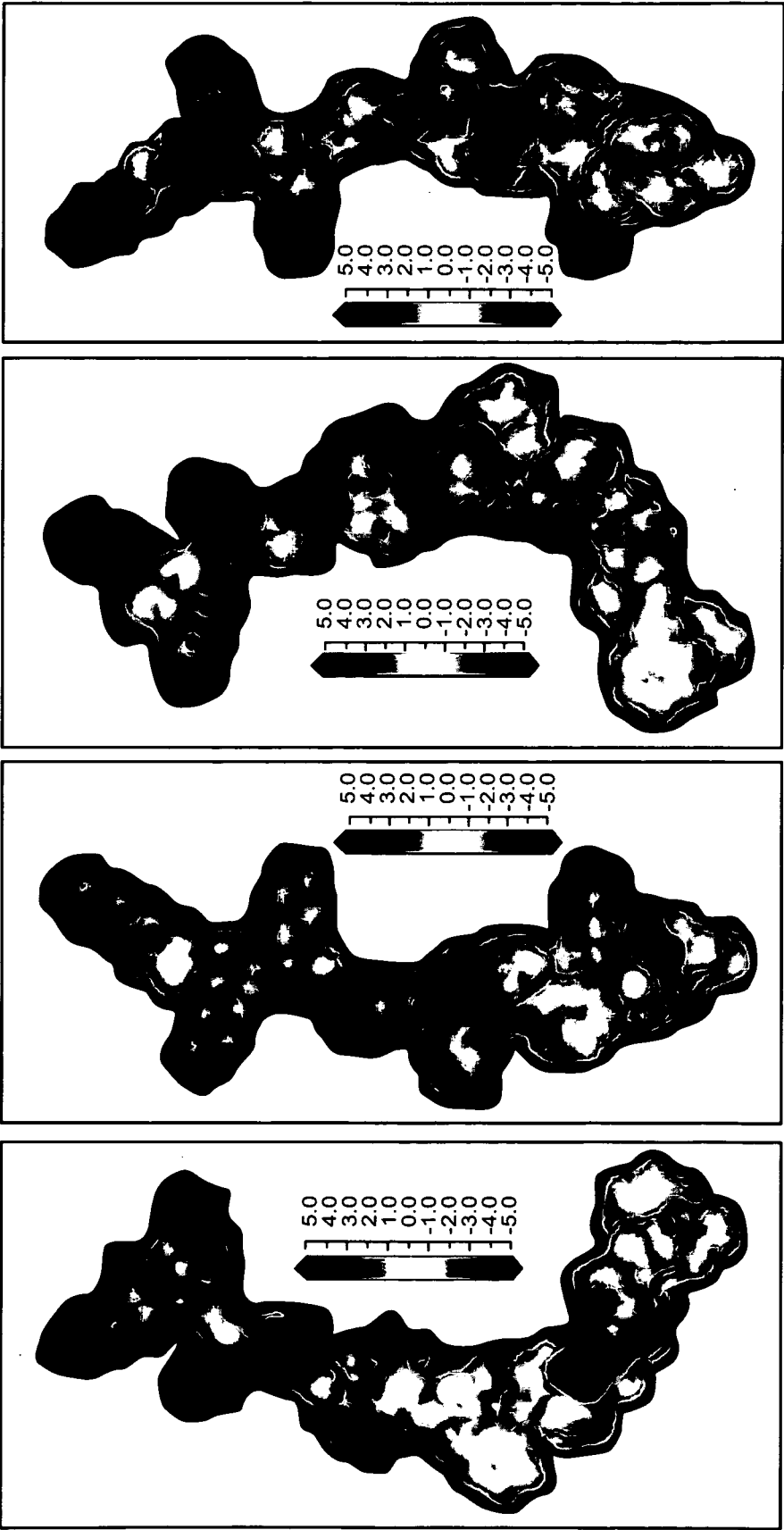
Fig. 3A



Polar Face

Fig. 3B

5/22



East Face

Fig. 4A

North Face

Fig. 4B

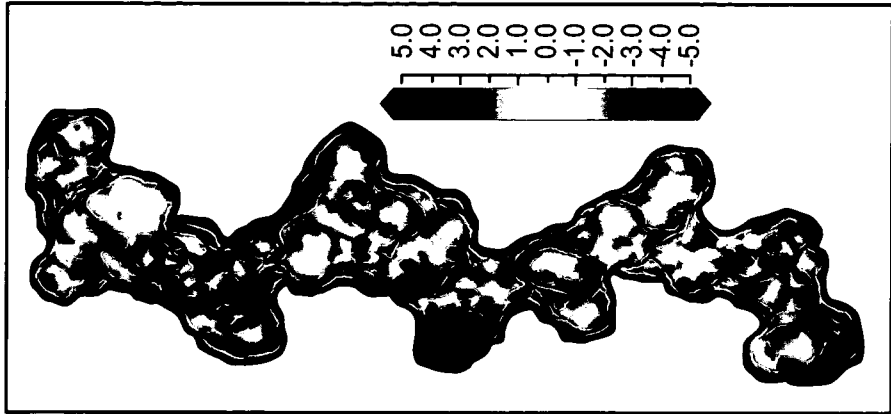
West Face

Fig. 4C

South Face

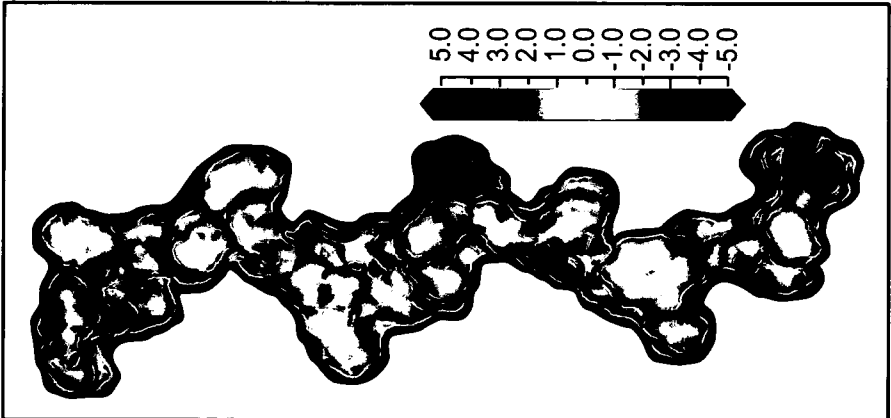
Fig. 4D

6/22



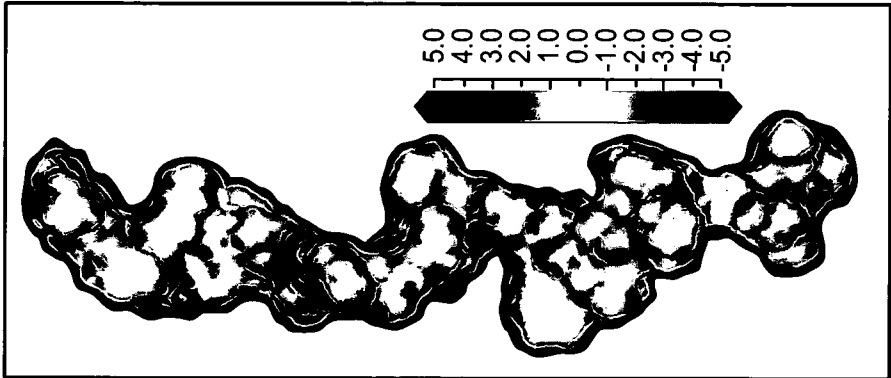
East Face

Fig. 5A



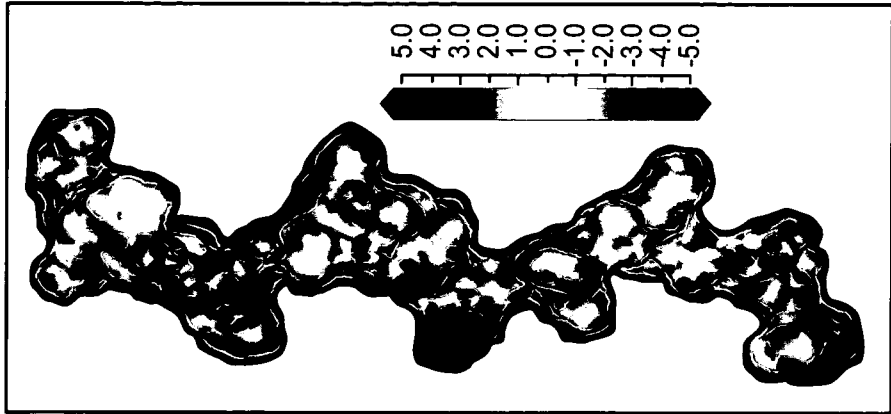
North Face

Fig. 5B



West Face

Fig. 5C



South Face

Fig. 5D

7/22

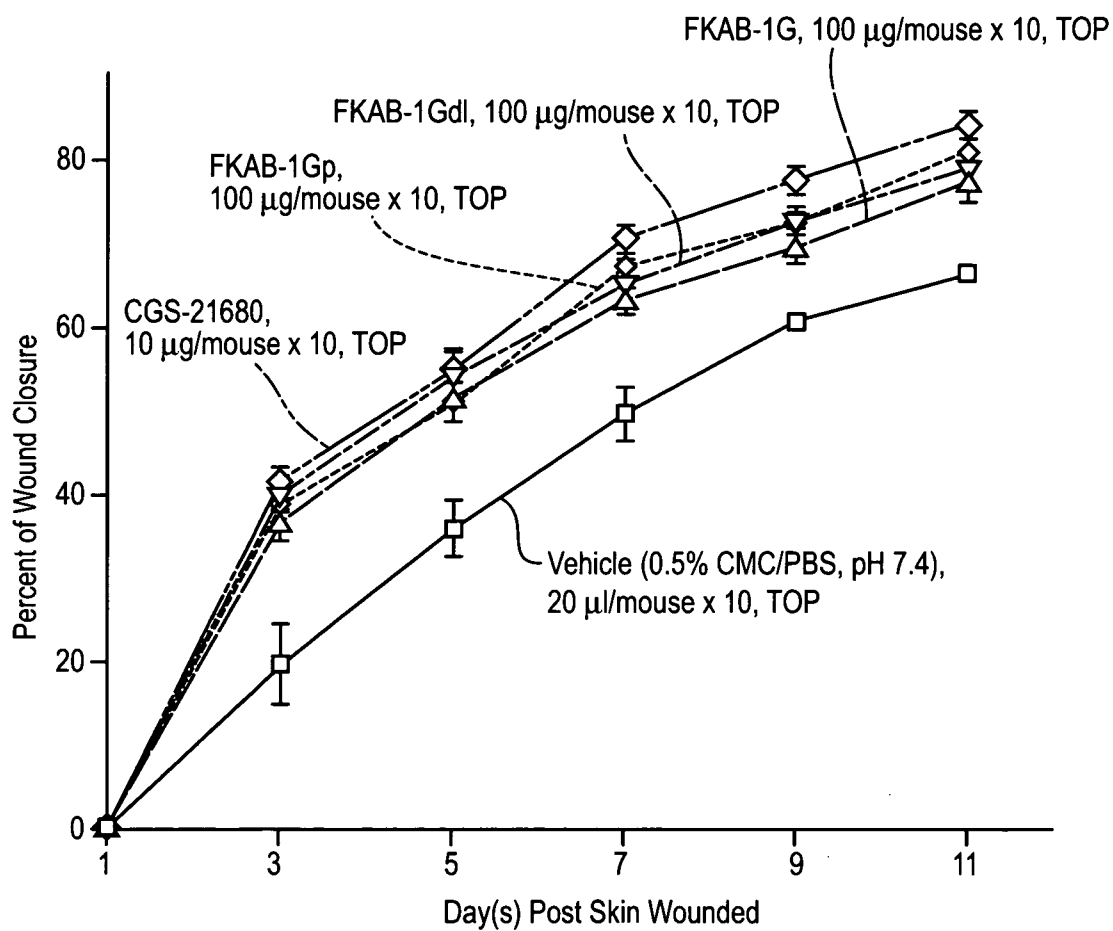


Fig. 6

8/22

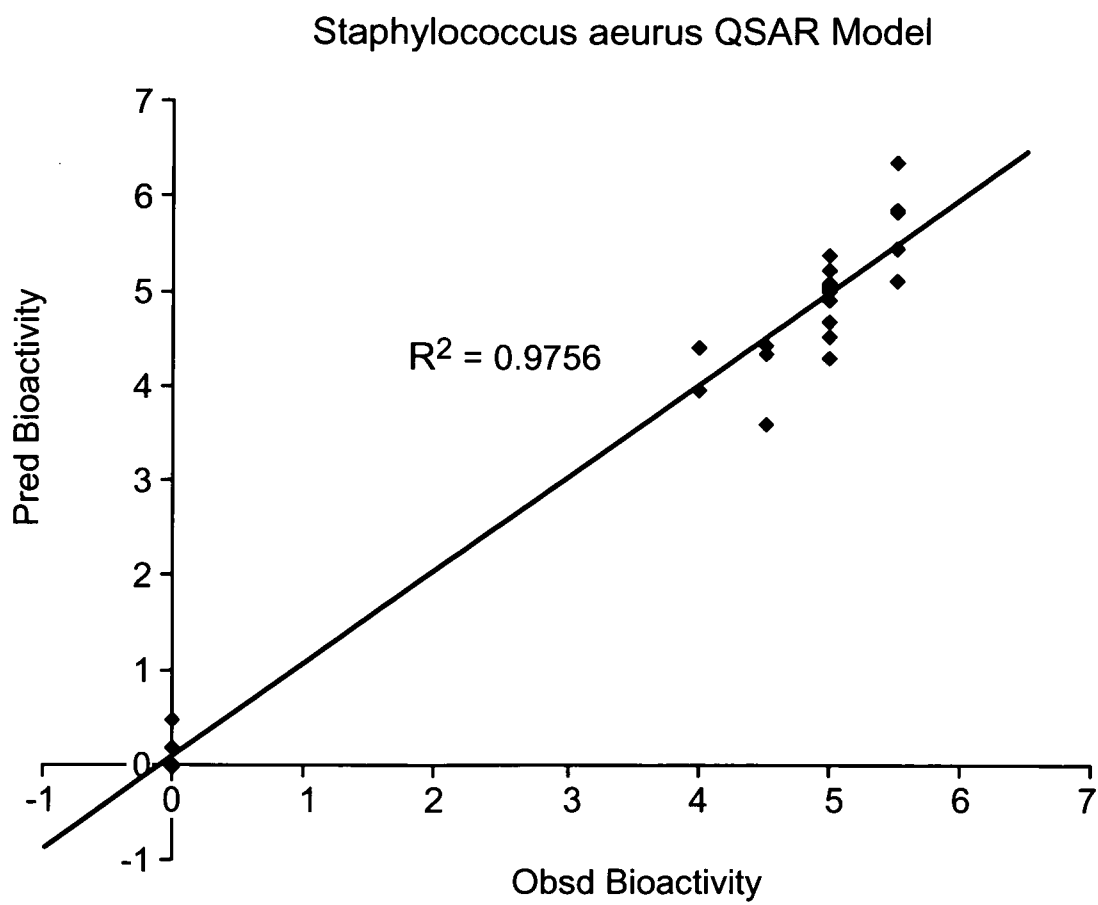


Fig. 7

9/22

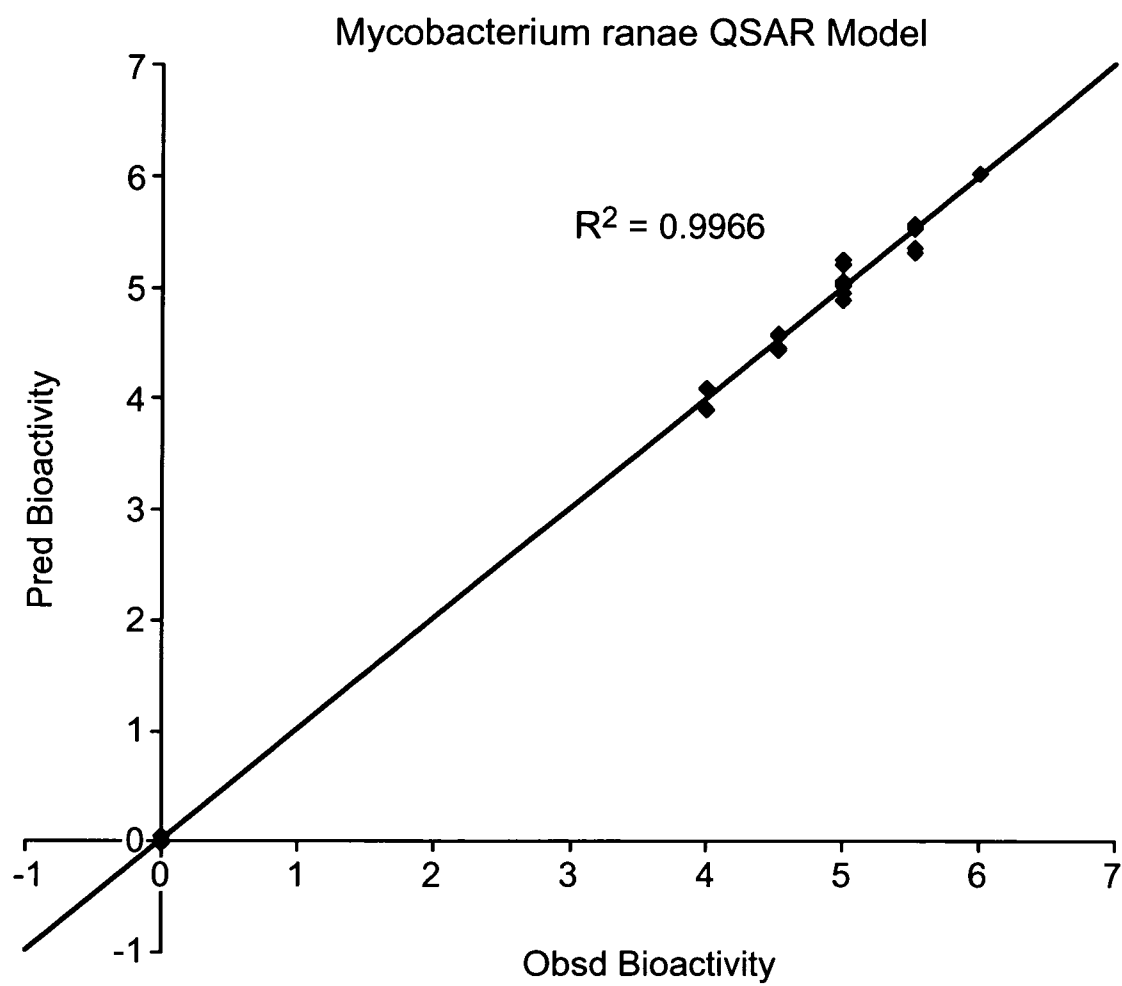


Fig. 8

10/22

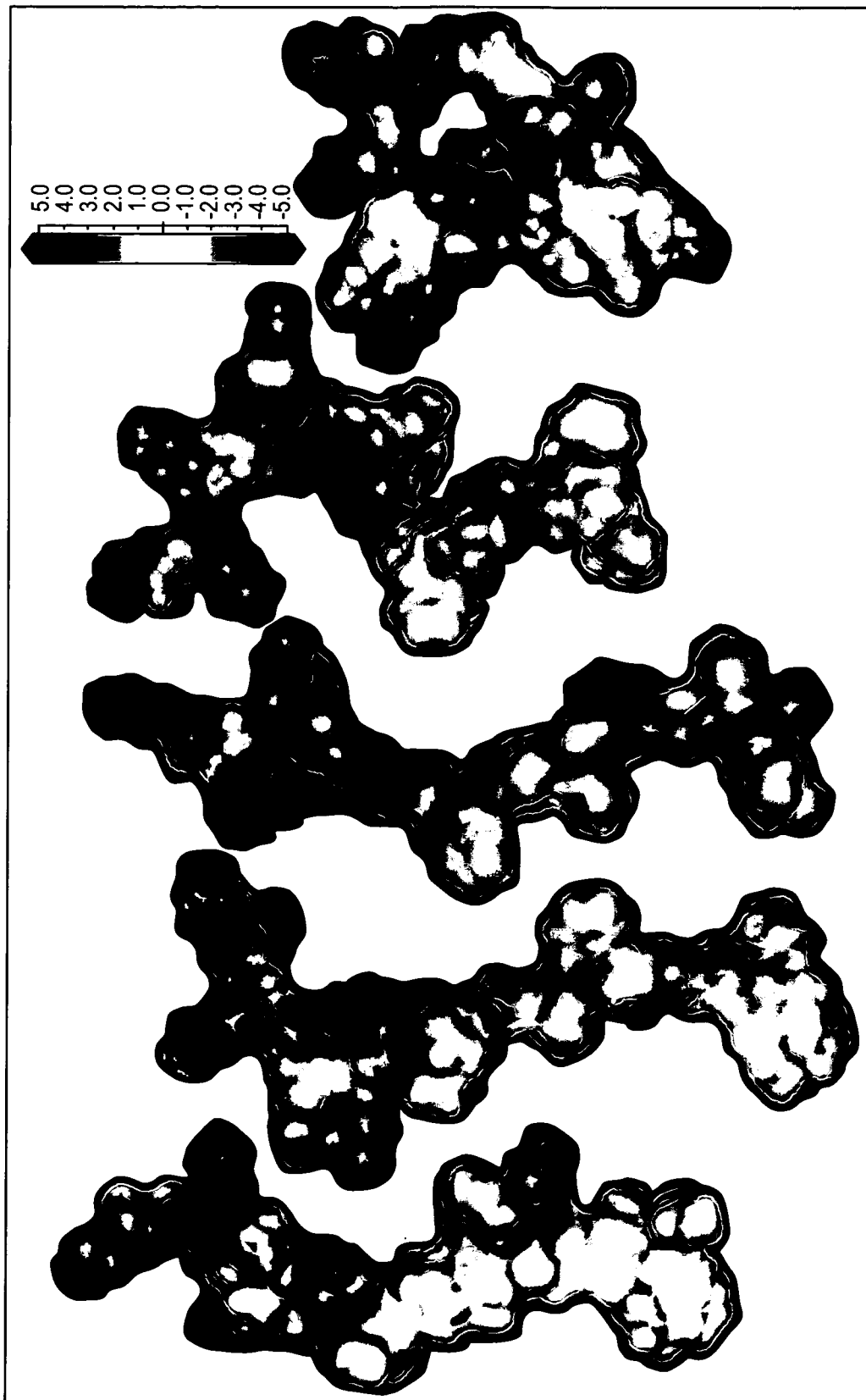


Fig. 9

11/22

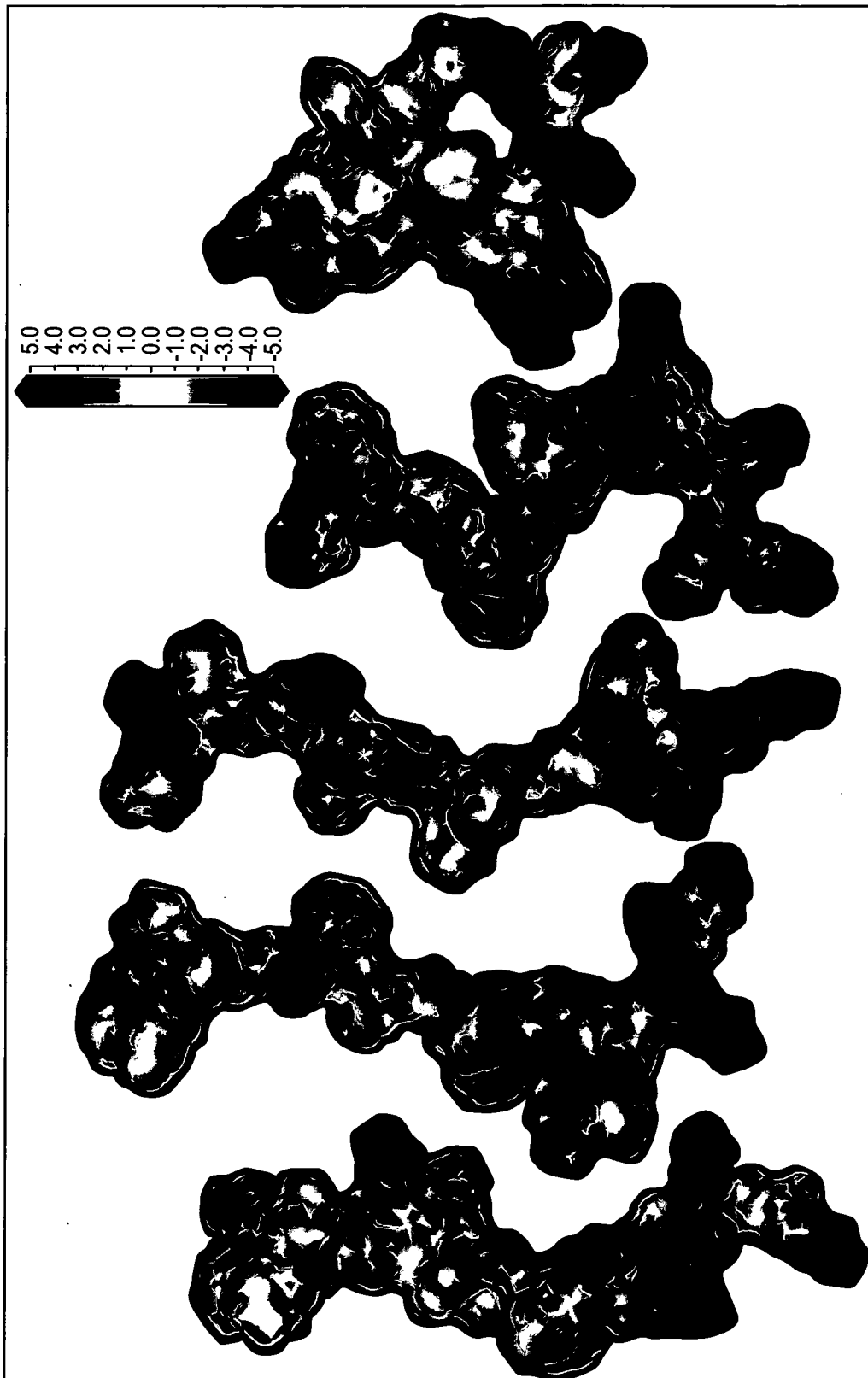


Fig. 10

12/22

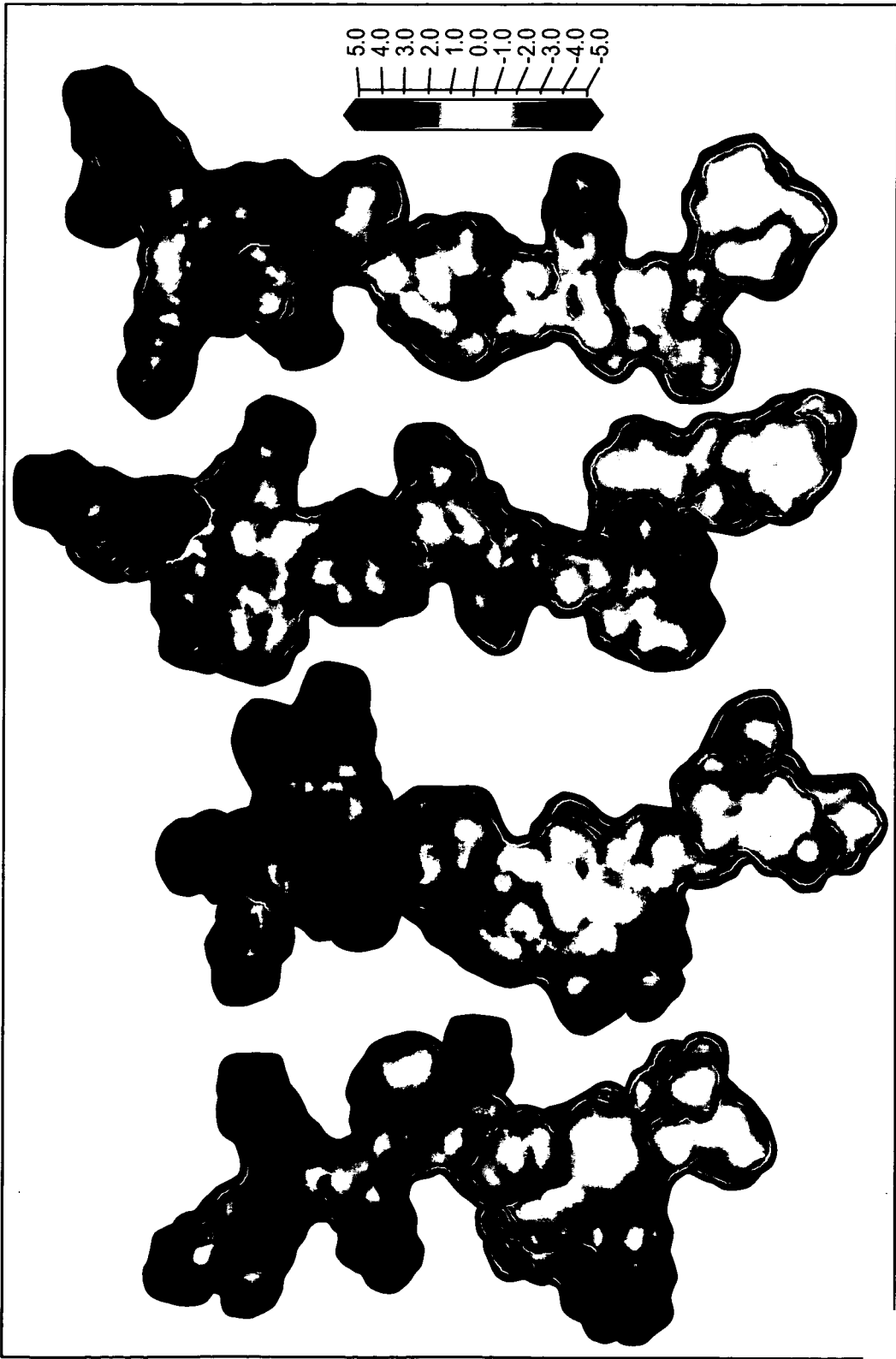


Fig.11

13/22

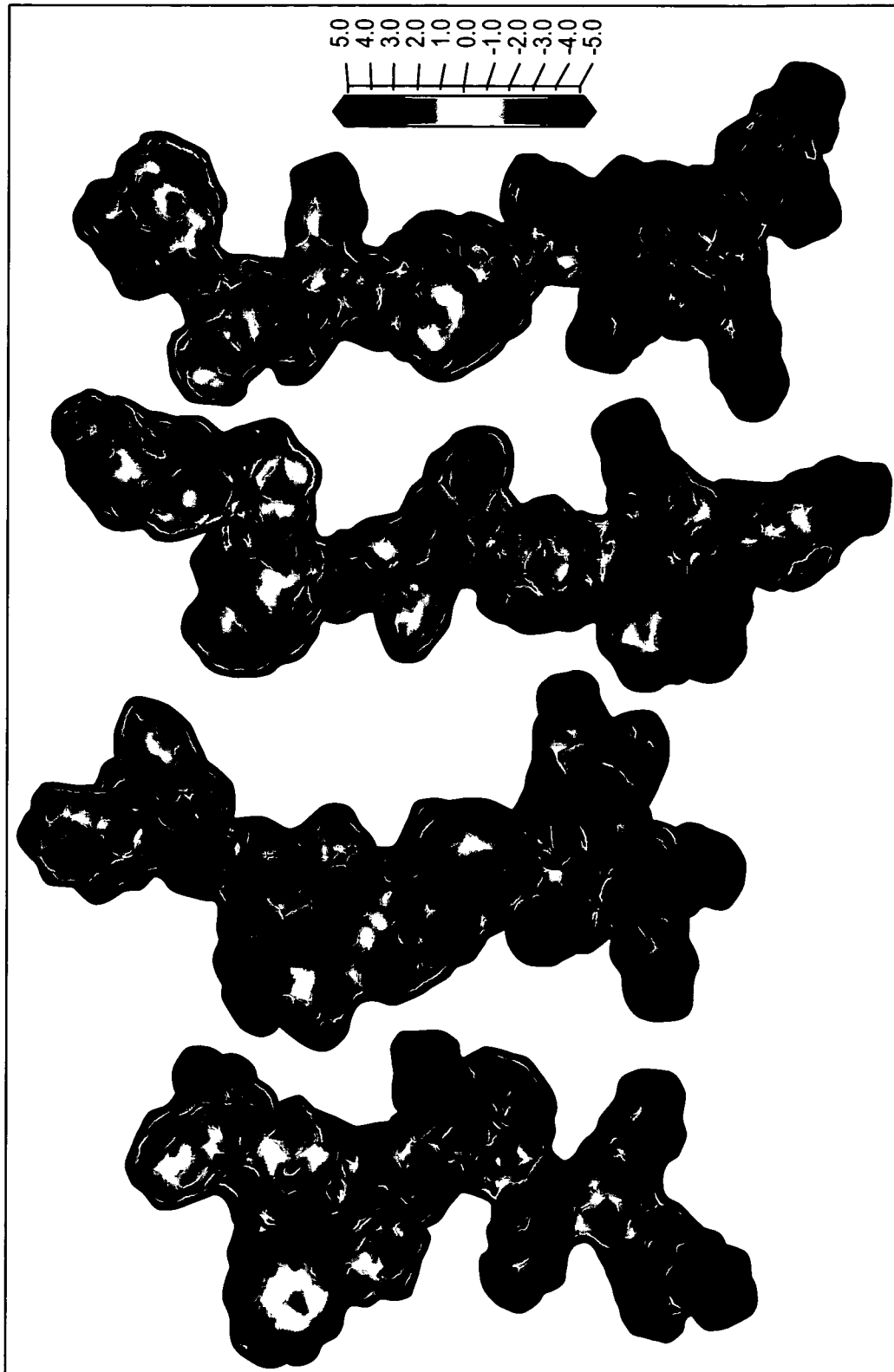


Fig. 12

14/22

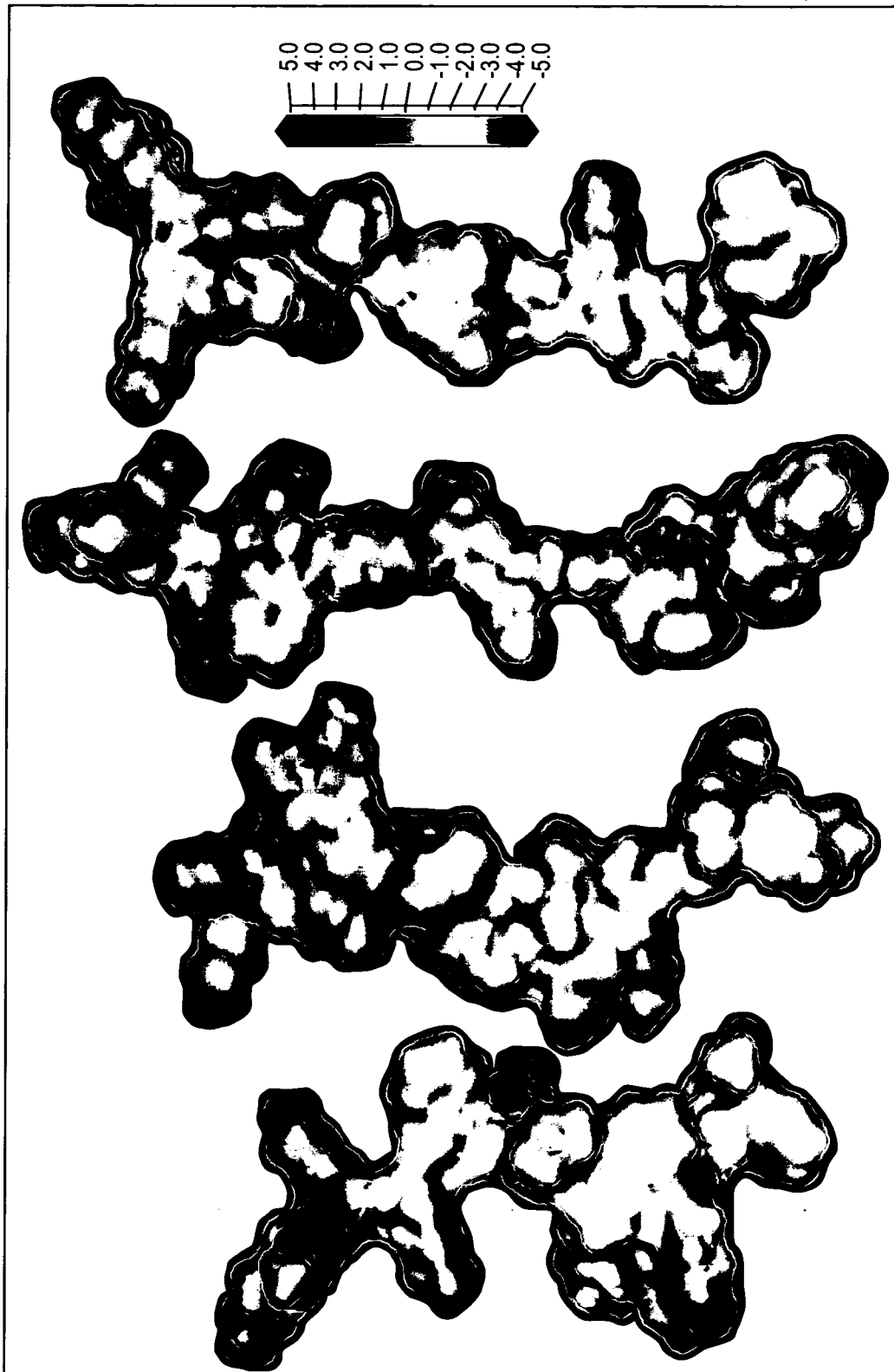


Fig. 13

15/22

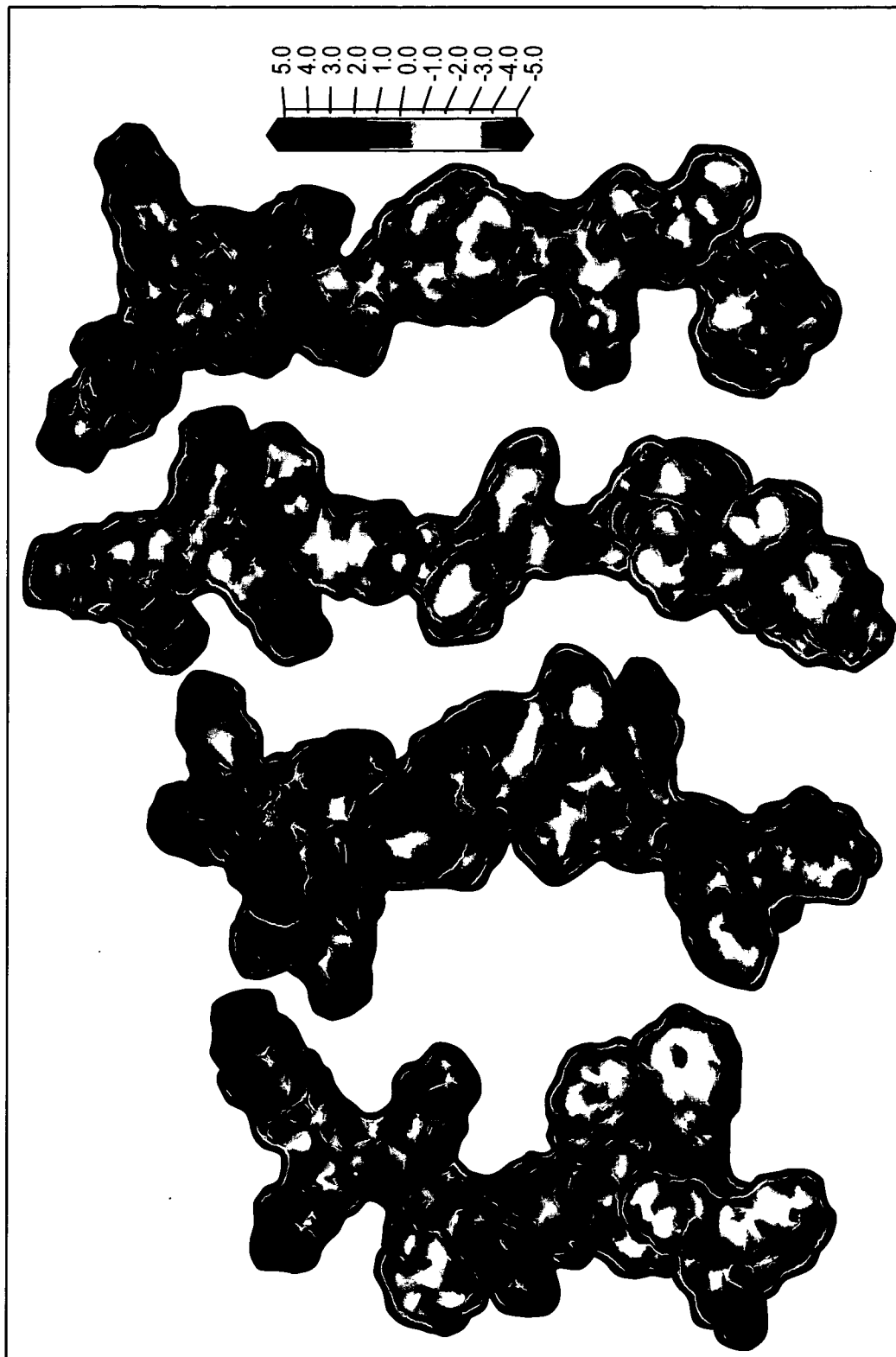


Fig. 14

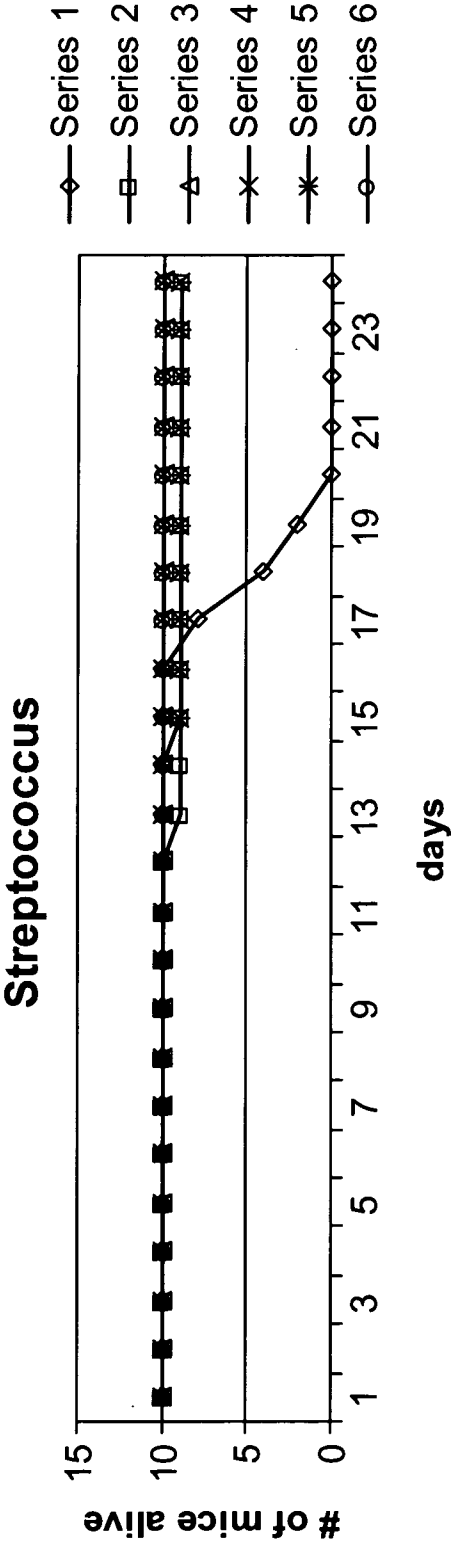


Fig.15

17/22

Salmonella typhimurium

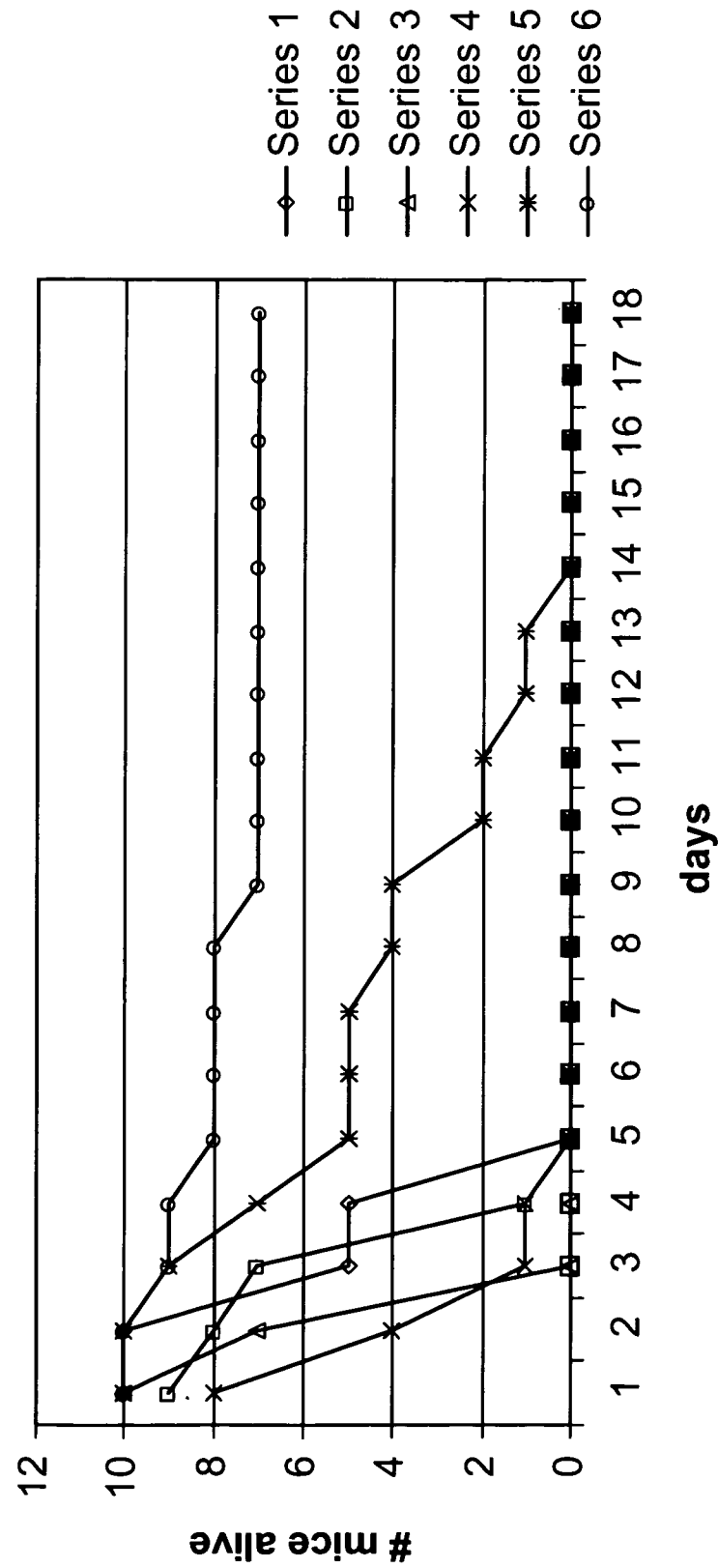
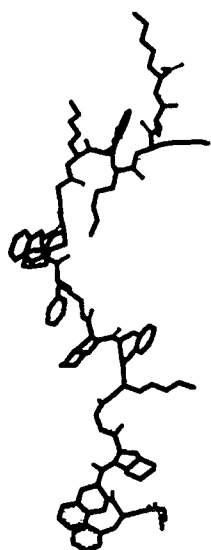
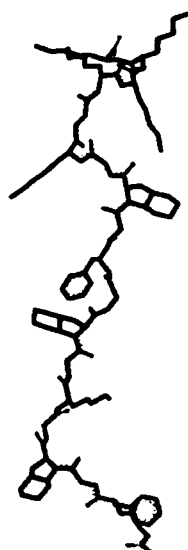


Fig.16

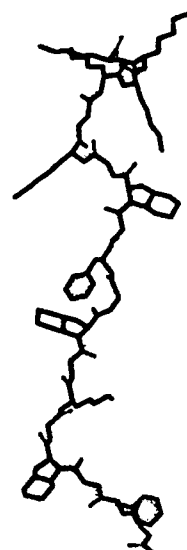
18/22



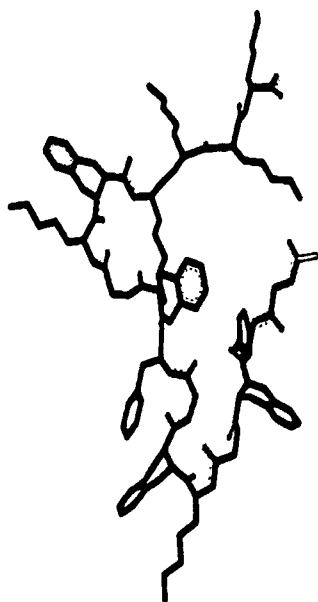
Compound 25



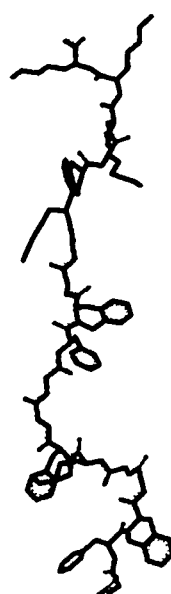
Compound 33



Compound 36



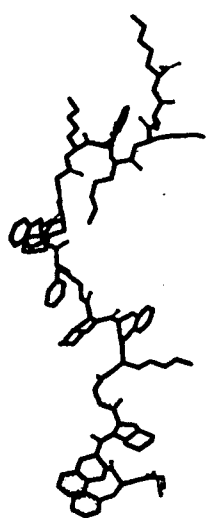
Compound 34



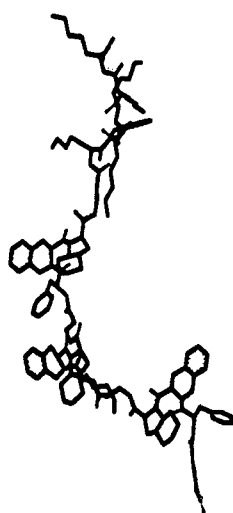
Compound 35

Fig. 17

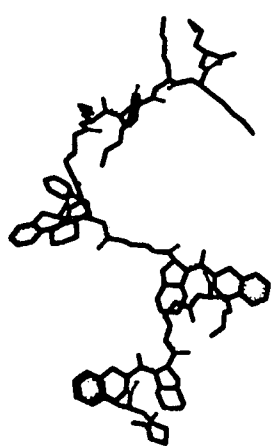
19/22



Compound 25



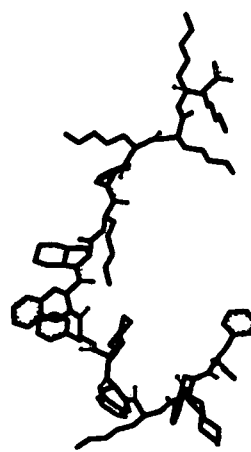
Compound 31



Compound 38



Compound 39



Compound 32

Fig. 18

20/22

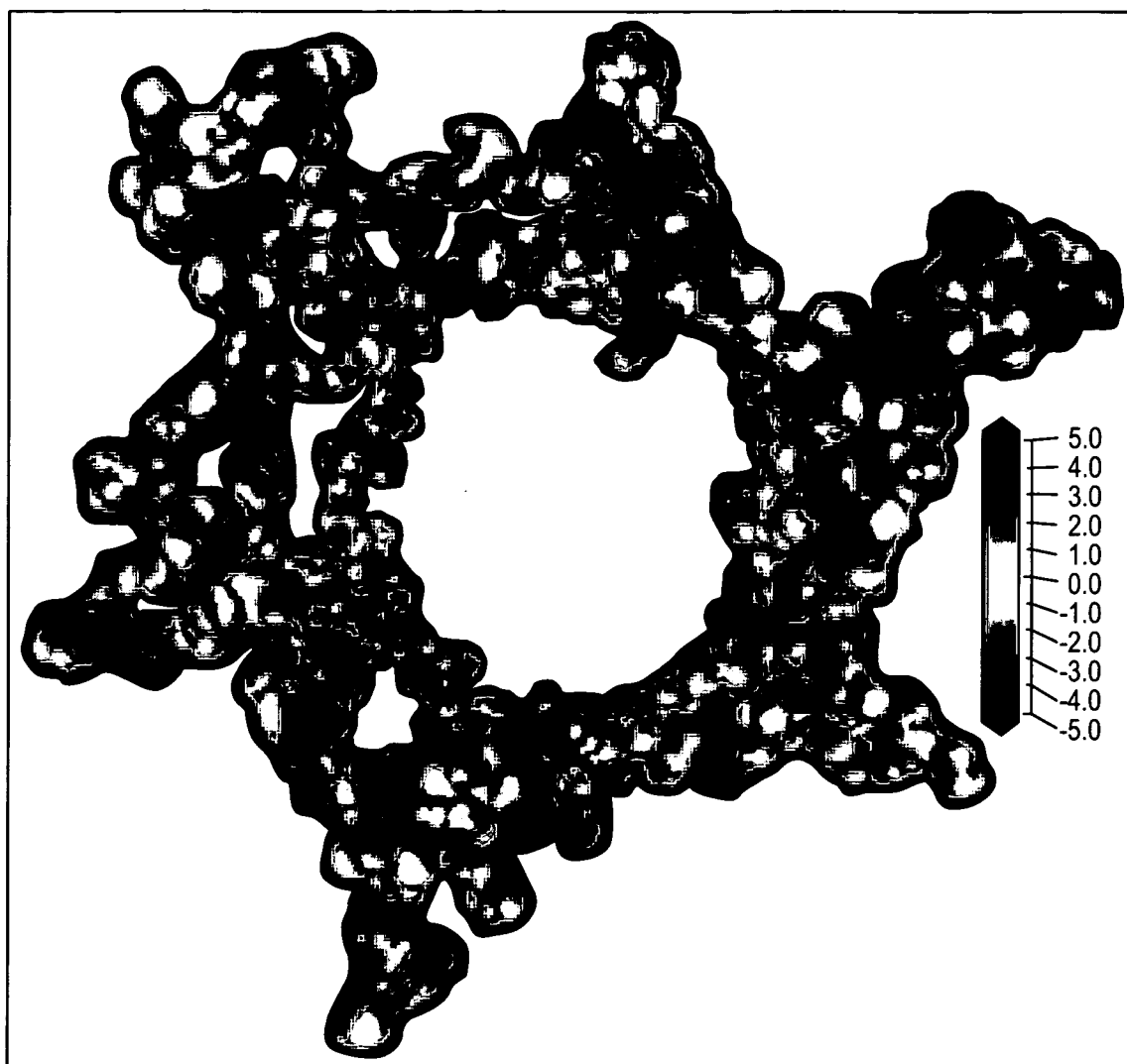


Fig. 19A

21/22

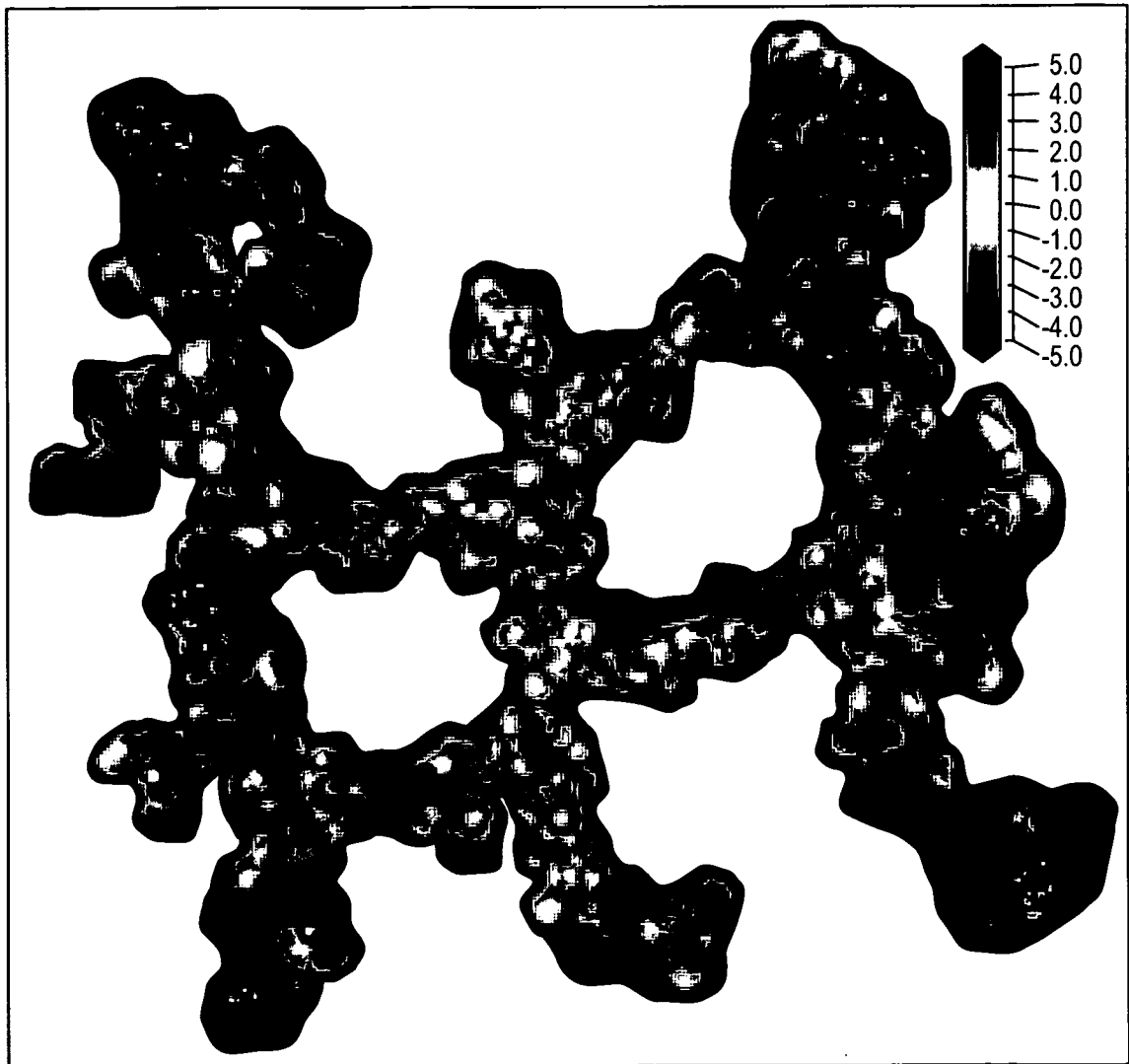


Fig. 19B

22/22

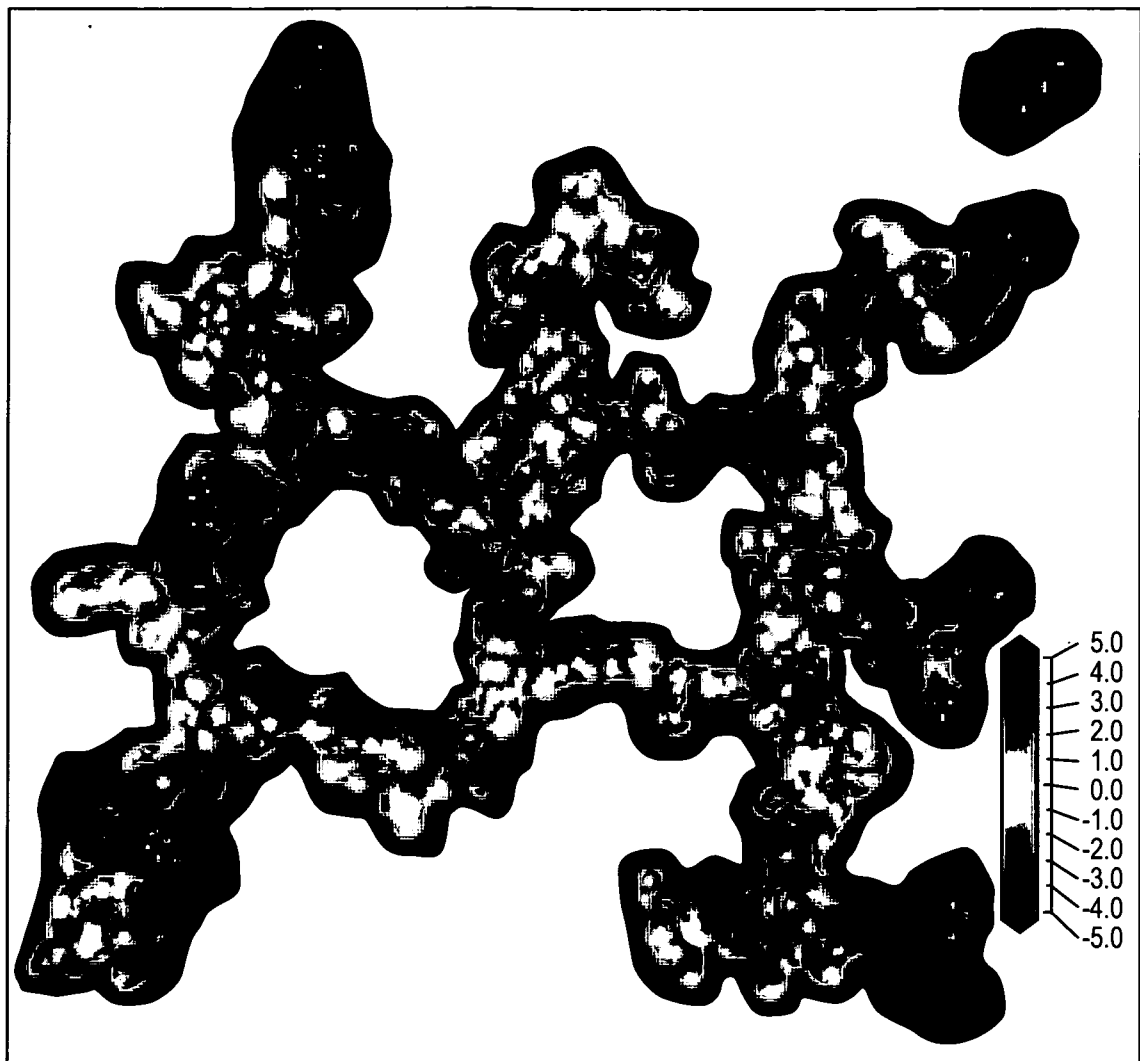


Fig. 19C