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CA 3064486 C 2023/08/01

(11)(21) 3 064 486

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 2018/03/12
(87) Date publication PCT/PCT Publication Date: 2018/10/25
(45) Date de délivrance/Issue Date: 2023/08/01
(85) Entrée phase nationale/National Entry: 2019/11/21
(86) N° demande PCT/PCT Application No.: CN 2018/078723
(87) N° publication PCT/PCT Publication No.: 2018/192323
(30) Priorité/Priority: 2017/04/20 (CN201710262440.8)

(51) Cl.Int./Int.Cl. *A61K 31/132* (2006.01),
A61P 35/00 (2006.01)

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(54) Titre : APPLICATIONS DE LA SPERMIDINE ET DE SON DERIVE
(54) Title: APPLICATIONS OF SPERMIDINE AND ITS DERIVATIVES

(57) Abrégé/Abstract:
Disclosed are applications of spermidine and its derivative. Based on existing protein structure data and small molecular data, the inventor performs screening by means of software-based computational analysis to obtain compounds that can effectively interfere with PAICS activity. After the compounds are used, the synthesis of SAICAR can be reduced, so that the purpose of treating or mitigating tumors. By using drugs in combination, it is likely to achieve a better effect of treating or mitigating tumors.

Abstract

Disclosed are applications of spermidine or its pharmaceutically acceptable derivatives. The inventors performed calculation and analysis using software based on existing data relating to protein and small-molecule structures, and screened out compounds which can effectively interfere with the activity of PAICS and thus reduce SAICAR synthesis, thereby achieving the goal of treating or improving tumors. It is expected to produce better effect in the treatment or improvement of tumors.

APPLICATIONS OF SPERMIDINE AND ITS DERIVATIVES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims priority to Chinese Patent Application No. 201710262440.8, filed on April 20, 2017.

TECHNICAL FIELD

The present disclosure relates to novel use of a compound, and particularly to the use of spermidine and the derivatives thereof.

BACKGROUND ART

One important hallmark of cancer cells is metabolic reprogramming, including increased glucose uptake and oxygen-independent lactate fermentation, which is also known as Warburg effect [1, 2]. Such reprogramming is necessary for the growth and survival of tumors, especially under pressure conditions such as ambienthypoxia. However, it is still unclear for the important molecular mechanism, as well as the action mode for the correlation of the metabolic reprogramming of tumor cells with the rapid proliferation, differentiation, migration and the like of tumors.

Pyruvate kinase isoform M2 (PKM2), as one important enzyme in metabolic process, is highly expressed in most tumor cells which undergo rapid proliferation, and has great influence on the metabolism and growth of tumor cells [3,4]. In addition, various pharmacological agents against PKM2 enzyme activity can affect the growth and proliferation of cells [5,6]. It also suggests that altering tumor metabolism by targeting the enzyme activity of PKM2would become a new approach for tumor therapy [7].

Purine metabolism is a ubiquitous and important biological metabolism in organisms. Its products, AMP and GMP, provide not only starting materials for the biosynthesis of DNA and RNA in the organisms, but also purine bases which are necessary for the *in vivo* synthesis of many key coenzymes (e.g. NAD, NADP, FAD

Date Reçue/Date Received 2021-06-23

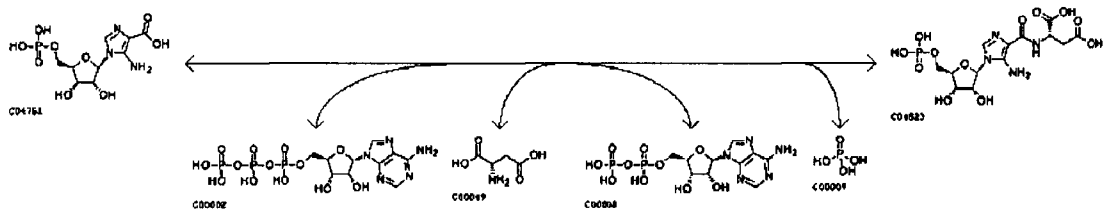
and CoA), signal molecules (e.g.cAMP) and an important energy molecule ATP. It is thus evident that the purinemetabolism is at the core position of the whole metabolic network. Purine synthesis comprises two synthetic pathways, i.e. *de novo* purine synthesis and salvage pathway.

In the adenine *de novo* synthesispathway, adenylosuccinatelyase (hereinafter referred to as ADSL enzyme) mainly participates in the catalyzing and cleaving of SAICAR to form AICAR and in the generation of AMP from S-AMP [Spiegel, E.K., Colman, R.F., and Patterson, D.(2006).*Adenylosuccinatelyase deficiency*.Mol Genet Metab 89, 19-31.Clamadieu, C., Cottin, X., Rousselle, C., and Claris, O.(2008).*Adenylosuccinatelyase deficiency: an unusual cause of neonatal seizure*.Arch Pediatr 15, 135-138.Castro, M., Perez-Cerda, C., Merinero, B., Garcia, M.J., Bernar, J., Gil Nagel, A., Torres, J., Bermudez, M., Garavito, P., Marie, S., et al.(2002).*Screening for adenylosuccinatelyase deficiency: clinical, biochemical and molecular findings in four patients*.Neuropediatrics 33, 186-189].

In human bodies, abnormal metabolic enzyme in theadenine*de novo*synthesis pathway often leads to the accumulation of deleterious intermediate metabolite succinyl-5-aminoimidazole-4-carboxamide-1-ribose-5-phosphate (SAICAR), which has clinicalsymptoms such as autism, epilepsy, hypotonia, and dysplasia [8-10]. SAICAR synthase is encoded by gene *PAICS* (*phosphoribosylaminoimidazolesuccinocarboxamidesynthetase /phosphoribosylaminoimidazolecarboxylase*), and is responsible for the synthesis of SAICAR *in vivo*.Related studies have reportedthat *PAICS* is highly expressed in acute lymphocytic leukemia, lung cancer, glioma, prostate cancer and colorectal cancer, and can be used as a prognostic marker for stage III colorectal cancer [11-13]. Recent studies have found that SAICAR can be highly accumulated under glucose-limited conditions, and thenalter energy level, sugar uptake, and generation of lactic acid in tumor cells. However, these phenomena are not found in adult epidermal cells and lung fibroblasts [14, 15].SAICAR can induce the enzymatic activity of PKM2 and promote the survival of tumor cells [14]. Moreover, the binding of SAICAR-PKM2 can induce the phosphorylation of Erk1/2, andSAICAR in high concentration can also

induce the up-regulated expression of oncogene *myc* [15]. The accumulated SAICAR due to abnormaladenine*de novo* synthesis pathway promotes the proliferation and survival of tumor cells.

Phosphoribosylaminoimidazole succinocarboxamidesynthetase/phosphoribosylaminoimidazolecarboxylase, i.e. PAICS, is an important bifunctional enzyme in the purine *de novo* synthesis pathway, and has the functions of SAICAR synthetase (4-(N-succinylcarboxamide)-5-aminoimidazole ribonucleotidesynthetase, SAICARs) and AIR carboxylase (5-aminoimidazole ribonucleotidecarboxylase, AIRc). PAICS catalyzes the sixth and seventh steps of the purine *de novo*synthesis, in which one key reaction process is shown as follows:



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Therefore, tumors having abnormally high expression of PAICS are often accompanied by the accumulation of deleterious metabolite SAICAR. Researches on inhibiting the expression of PAICS or its enzymatic activity will become new means for tumor therapy. It is very important to develop or screen out compounds that can effectively inhibit theactivity of PAICS.

Spermidine is an important polyamine in vivo, and plays an important role inlife activities of living organisms andinvolves in many processes such as cell migration, cell growth and tumorigenesis. Spermidine also plays an important role in the maintenanceof the structure stability of DNA, RNA and cell membranes, in the synthesis of proteins, and in the regulation of ion channels. The catabolism of spermidine may produce many metabolites such as free radicals, and may influence cell vitality. Spermidine is often overexpressed in tumor tissues, as disclosed byauthoritative papers such as Criss W E.A Review of Polyamines and Cancer[J].*Turkish Journal of Medical Sciences*, 2003, 33(4): 195-205.; Gerner EW,

Meyskens FL Jr.Polyamines and cancer: old molecules, new understanding.[J].*Nat Rev Cancer*. 2004, 4(10): 781-792.; Rial NS, Meyskens FL, Gerner EW.Polyamines as mediators of APC-dependent intestinal carcinogenesis and cancer chemoprevention[J].*Essays in biochemistry*, 2009, 46(Suppl.1): 111.; Amendola R, Cervelli M, Fratini E, et al. Spermine metabolism and anticancer therapy[J]. *Current cancer drug targets*, 2009, 9(2): 118-130.; Mandal S, Mandal A, Johansson H E, et al.Depletion of cellular polyamines, spermidine and spermine, causes a total arrest in translation and growth in mammalian cells[J]. *Proceedings of the National Academy of Sciences of the United States of America*, 2013, 110(6): 2169-74. It has long been knownthat spermidine can promote the development of tumor cells and is a tumor promoter. Therefore, it is conductive to cancer-fightingby reducing the supply of spermidine.

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SUMMARY OF THE INVENTION

An objective of the present disclosure is to provide use of aclass of compounds interfering with the activity of SAICAR synthase.

The inventors, on the basis of existing data relating to protein and small-molecule structures, performed calculation and analysis using software, and found that a compound with DrugBank ID DB03566 (general name: spermidine) can effectively interfere with the activity ofPAICS and thus reduce SAICAR synthesis, thereby achieving the goal of treating or improving tumors.

The tumor may be one having any property selected from Warburg effect, high expression of oncogene *myc*, high expression of PAICS, being associated with Erk1/2, and high expression of *PKM2* gene. In particular, the tumor may be selected from acute lymphocytic leukemia, lung cancer, glioma, prostate cancer, colorectal cancer, gastric cancer, liver cancer, esophageal cancer, colon cancer, malignant lymphoma, cervical cancer, nasopharyngeal cancer, breast cancer, skin canceror bladder cancer, and especiallymay be selected from acute lymphocytic leukemia, lung cancer, glioma, prostate cancer or colorectal cancer which have thehigh expression of PAICS.

As used herein, the term"high expression" has the meaning well known in the art, and refers tothe expression which is significantly increasedas compared to that of a normal tissue.

The pharmaceutically acceptable derivatives of the above compound may have the same parent core structure as the compound per se, and can produce molecules having the same or similar activity as the original compound through*in vivo* reactions such as hydrolysis and the like. Thus, thepharmaceutically acceptable derivativescan havethe same or similar therapeutic effect as that of the original compound.

The pharmaceutically acceptable derivatives of the compound may particularly refer to simple derivatives thereof, especially to one of lower ester, lower ether, lower alkyl substituent, a medicinal salt and lower amide thereof. That is, the pharmaceutically acceptable derivatives may be derivatives obtained by a condensation reaction between the parent compoundwithcarboxylic acid, alcohol or amine having 1 to 6, preferably 2 to 6, and 2 to 4 carbon atom(s).

The pharmaceutically acceptable medicinal salt of the compound can be synthesized from the parent compound by a conventional chemical method, such as the method described in *Pharmaceutical Salts: Properties, Selection and Use*, P Heinrich Stahl (Editor), Camille G. Wermuth (Editor), ISBN: 3-90639-026-8, Hardcover, 388 pages, August 2002. In general, such salts can be prepared by reacting free alkali of the compound with an acid in water,an organic solvent or a mixed solution of both, generally in anon-aqueous media such as diethyl ether, ethyl acetate, ethanol, isopropanol or acetonitrile.

The acid addition salt can be prepared using various acids such as inorganic and organic acids. The examples of the acid addition salt may include salts prepared from acids, which may be selected from a group consisting of acetic acid, 2,2-dichloroacetic acid, adipic acid, alginic acid, ascorbic acid (e.g. L-ascorbic acid), L-aspartic acid, benzenesulfonic acid, benzoic acid, 4-acetylamino benzoic acid, butyric acid, (+)-camphoric acid, camphor sulfonic acid, (+)-(1S)-camphor-10-sulfonic acid, capric acid, hexanoic acid, octanoic acid, cinnamic acid, citric acid, cyclamic acid, dodecylsulfuric acid, ethane-1,2-disulfonic acid, ethanesulfonic acid, 2-hydroxyethanesulfonic acid, formic acid, fumaric acid, galactonic acid, gentisic acid, glucoheptonic acid, D-gluconic acid, glucuronic acid (e.g. D-glucuronic acid), glutamic acid (e.g. L-glutamic acid), α-ketoglutaric acid, glycolic acid, hippuric acid, hydrobromic acid, hydrochloric acid, hydroiodic acid, isethionic acid, (+)-L-lactic acid, (±)-DL-lactic acid, lactobionic acid, maleic acid, malic acid, (-)-L-malic acid, malonic acid, (±)-DL-mandelic acid, methanesulfonic acid, naphthalene-2-sulfonic acid, naphthalene-1,5-disulfonic acid, 1-hydroxyl-2-naphthoic acid, nicotinic acid, nitric acid, oleic acid, orotic acid, oxalic acid, palmitic acid, pamoic acid, phosphoric acid, propionic acid, L-pyroglutamic acid, salicylic acid, 4-aminosalicylic acid, sebacic acid, stearic acid, succinic acid, sulfuric acid, tannic acid, (+)-L-tartaric acid, sulfocyanic acid, *p*-toluenesulfonic acid, undecylenic acid,pentanoic acid, andacylated amino acids.

With combined utilizationof at least two of the above compounds, it is expected to obtain better effect of treating and improving tumors.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 showsthe 3D solid ribbon structurediagram of PAICS;

Fig. 2 showsthe diagrams indicating the interaction of the crystal structures of CAIR and SAICAR synthetase, in which A: PDB access ID 2GQS; B: PDB access ID 2CNQ; and C: PDB access ID 4FE2;

Fig. 3 showsthe alignment result of the protein sequences ofSAICAR synthetases from different species;

Fig. 4 showsthe experimental result indicating theinhibition of spermidine on oncogene *MY*;

Fig. 5 shows the diagram indicating the influence of spermidineon the viabilityof cells.

DETAILED DESCRIPTION OF THE EMBODIMENTS

There are 425 amino acid residues in the full length of the human PAICS protein sequence, in which 2-260AA is a SAICAR synthetase domain and 267-425AA is AIR carboxylase domain, these two domains are linked by a peptide chain consisting of 6 amino acid residues(KSESQC). Furthermore, GLN159-GLN183 α-helix in the SAICAR synthetase domain and ASN395-ASN424 α-helix in the AIR carboxylase domaininteract with each other and are tightly bound together, as shown in Fig. 1.

SAICAR synthetase crystal structure data of different origins are collectedin a protein structure database (RCSB), which includes*Saccharomyces cerevisiae* (1A48, 2CNQ, 2CNV, 2CNU, 1OBD, 1OBG), *Pyrococcushorikoshii OT3* (3U54, 3U55), *Escherichia coli* (2GQR, 2GQS),*Methanocaldococcusjannaschii* (2YZL, 2Z02), *Streptococcus pneumonia* (4FGR, 4FE2), *Mycobacterium abscessus*ATCC 19977/DSM 44196 (3R9R), *Thermotoga maritime* (1KUT), *Clostridium perfringens* (3NUA), *Ehrlichiachaffeensis* (3KRE), *Geobacilluskaustophilus*(2YWV), as well as PAICS crystal structure data of *Homo sapiens* (2H31) and *Bombyxmori* (4JA0).Wherein, the complexes containing the structure of CAIR are 2GQS, 2CNQ and 4FE2, and the complexes containing the structure of ASP are 2CNV, 2CNU and 4FE2.

As shown in Fig. 2, the residues within CAIR 3Å in 2CNQ comprise Arg122, Ser128, ASP215, Arg242 and Arg264; the residues within CAIR 3Å in 2GQScomprise Arg94, Ser100, ASP129, ASP175, Arg199 and Arg215; and the residues within CAIR 3Å in 4FE2 comprise Arg93, Ser99, ASP174, Arg199 and Arg214. As can be seen from the alignment results of SAICAR protein sequences from different species (Fig. 3), it is highly conservative for the sequence, whichbinds

with CAIR, of SAICAR synthetasesfrom different species, and CAIR is primarily fixed by hydrogen bonds.

On the basis of the above results, the crystal structureconformations in SAICAR synthetases of*Saccharormyces cerevisiae* (PDB:2CNQ) and *Escherichia coli* (PDB:2GQS) are used as receptor structures for calculating and screening, since there is no conformation which can bind CAIR in human PAICS crystal structure, and is no catalytic conformation formed in the catalytic region,and the results obtained by calculation thereofwould beunreliable. 4661 of small molecule drugs in DrugBank (http://www.drugbank.ca/downloads#structures) are calculated and screened by using ligand fit module of Discovery studio.

The calculation results show that DB03566 (general name: Spermidine) has a Dock Score of 239.22, indicating that the compound spermidine can effectively interact with PAICS, and influence the synthesis of SAICAR.Thus, it can be expected to develop into tumor-treating medicines or health care products.Said tumor may be one having any property selected from Warburg effect, high expression of oncogene *myc*, high expression of PAICS, being associated with Erk1/2 and high expression of PKM2 gene. In particular, said tumor may be selected from acute lymphocytic leukemia, lung cancer, glioma, prostate cancer, colorectal cancer, gastric cancer, liver cancer, esophageal cancer, colon cancer, malignant lymphoma, cervical cancer, nasopharyngeal cancer, breast cancer, skin cancer orbladder cancer, andespecially be acute lymphocytic leukemia, lung cancer, glioma, prostate cancer or colorectal cancer which has high expression of PAICS.

Experimentalresult data ofthe inhibition of spermidine on PAICS activity

It is confirmed by further biochemical enzyme activity experiments and cell biology experiments that the compound spermidinecan inhibit the accumulation of SAICAR up to68.98%. The accumulation of toxic compound SAICAR is reduced by inhibiting the activity of PAICS.

Experimentalresult data of theinhibition of spermidine on oncogene *MYC*

It is confirmedby further cell biology experiments and Western Blot experiments that the compound spermidine can significantly inhibit the expression of oncogene *myc*,such that the expression of oncogene mycis significantly down-regulated(the results of Western Blot are shown in Fig. 4).

Experimentalresult data of theinhibition of spermidine on cancer cells

It is confirmed by further cell biology experiments that the compound spermidinecan effectively inhibit the growth of cells from a lung cancer cell strain A549, lung cancer cell strains H1299 and PC9, a breast cancer cell strain MD468, and a breast cancer cell strain MD231. Fig. 5 shows the cell viability under different concentrations of spermidine. IC_{50} values after 48 hours of drug administration are shown in table below. The experimental results demonstrate that spermidine hassignificant anti-cancer effect.

Cancer cells	IC_{50} (μM)
A549	52.1
H1299	21.1
PC9	23.4
MD468	46.1
MD231	1.41

The above calculation data and experimental data indicate that spermidine and pharmaceutically acceptable derivatives thereof can be developed as therapeutic drugs or health care products for tumors, especially tumor having any propertyselected from Warburg effect, high expression of oncogene *myc*, high expression of PAICS, being associated with Erk1/2 and high expression of PKM2 gene.In particular, the tumor may be selected from acute lymphocytic leukemia, lung cancer, glioma, prostate cancer, colorectal cancer, gastric cancer, liver cancer, esophageal cancer, colon cancer, malignant lymphoma, cervical cancer, nasopharyngeal cancer, breast cancer, skin canceror bladder cancer. The tumor may especially be acute lymphocytic leukemia,

lung cancer, glioma, prostate cancer or colorectal cancer which has high expression of PAICS.

The pharmaceutically acceptable derivatives of compound spermidinehave the same parent core structure as the compound per se, and can produce molecules having the same or similar activity as the original compound through *in vivo* reactions such as hydrolysis and the like. Thus, thepharmaceutically acceptable derivatives can have the same or similar therapeutic effect as that of the original compound.

The pharmaceutically acceptable derivatives of the compound particularly refers to simple derivatives thereof, especially to one of lower ester, lower ether, lower alkyl substituent, a medicinal salt and lower amide thereof. That is, the pharmaceutically acceptable derivatives may be derivatives obtained by a condensation reaction between the parent compoundwith carboxylic acid, alcohol or amine having 1 to 6, preferably 2 to 6, and 2 to 4 carbon atom(s).

The pharmaceutically acceptable medicinal salt of the compound can be synthesized from the parent compound by a conventional chemical method, such as the method described in *Pharmaceutical Salts: Properties, Selection and Use*, P Heinrich Stahl (Editor), Camille G. Wermuth (Editor), ISBN: 3-90639-026-8, Hardcover, 388 pages, August 2002.In general, such salts can be prepared by reacting free alkali of the compound with an acid in water, an organic solvent or a mixed solution containing the both, generally in non-aqueous media such as diethyl ether, ethyl acetate, ethanol, isopropanol or acetonitrile.

The acid addition salt can be prepared using various acids (inorganic and organic acids). The examples of the acid addition salt includes salts prepared from acids, which may be selected from a group consisting of acetic acid, 2,2-dichloroacetic acid, adipic acid, alginic acid, ascorbic acid (e.g. L-ascorbic acid), L-aspartic acid, benzenesulfonic acid, benzoic acid, 4-acetylamino benzoic acid, butyric acid, (+)-camphoric acid, camphor sulfonic acid, (+)-(1S)-camphor-10-sulfonic acid, capric acid, hexanoic acid, octanoic acid, cinnamic acid, citric acid, cyclamic acid, dodecylsulfuric acid, ethane-1,2-disulfonic acid, ethanesulfonic acid, 2-hydroxyethanesulfonic acid, formic acid, fumaric acid, galactonic acid, gentisic acid,

glucoheptonic acid, D-gluconic acid, glucuronic acid (e.g. D-glucuronic acid), glutamic acid (e.g. L-glutamic acid), α-ketoglutaric acid, glycolic acid, hippuric acid, hydrobromic acid, hydrochloric acid, hydroiodic acid, isethionic acid, (+)-L-lactic acid, (±)-DL-lactic acid, lactobionic acid, maleic acid, malic acid, (-)-L-malic acid, malonic acid, (±)-DL-mandelic acid, methanesulfonic acid, naphthalene-2-sulfonic acid, naphthalene-1,5-disulfonic acid, 1-hydroxyl-2-naphthoic acid, nicotinic acid, nitric acid, oleic acid, orotic acid, oxalic acid, palmitic acid, pamoic acid, phosphoric acid, propionic acid, L-pyroglutamic acid, salicylic acid, 4-aminosalicylic acid, sebacic acid, stearic acid, succinic acid, sulfuric acid, tannic acid, (+)-L-tartaric acid, sulfocyanic acid, p-toluenesulfonic acid, undecylenic acid,pentanoic acid, andacylated amino acids.

It can improve,to a certain extent, the therapeutic effect and reduce the toxic and side effect by combined usage of drugs. Preferably, two, three, four, five or more of the compounds or derivatives thereof can be used simultaneously as the active ingredients for the treatment of tumors.

What is claimed is:

1. A pharmaceutical composition for use in treatment of a tumor in a patient, wherein the composition comprises spermidine or a pharmaceutically acceptable salt thereof, and a pharmaceutically acceptable carrier,

wherein the tumor of the patient has been determined to have high expression of phosphoribosylaminoimidazole succinocarboxamide synthetase / phosphoribosylaminoimidazole carboxylase (PAICS).

2. The pharmaceutical composition for the use according to claim 1, wherein the composition further comprises a pharmaceutically acceptable excipient.

3. The pharmaceutical composition for the use according to claim 1 or 2, wherein the tumor is selected from the group consisting of acute lymphocytic leukemia, lung cancer, glioma, prostate cancer, colorectal cancer, gastric cancer, liver cancer, esophageal cancer, colon cancer, malignant lymphoma, cervical cancer, nasopharyngeal cancer, breast cancer, skin cancer and bladder cancer, each of which has high expression of PAICS.

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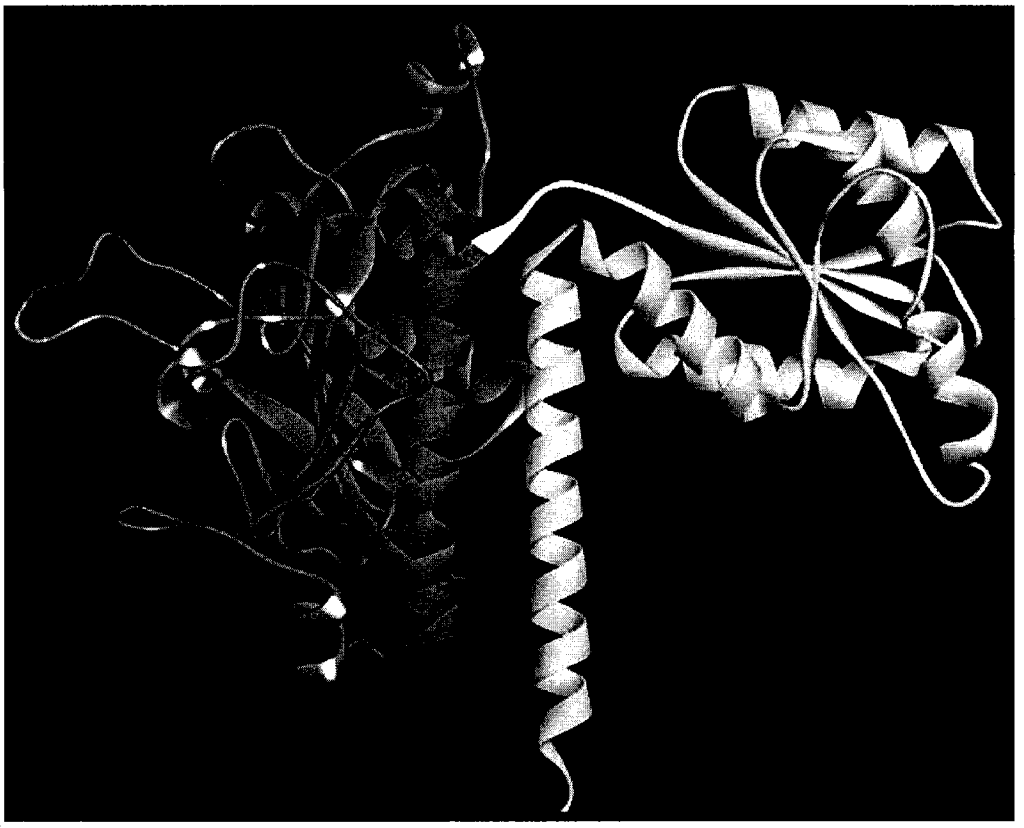
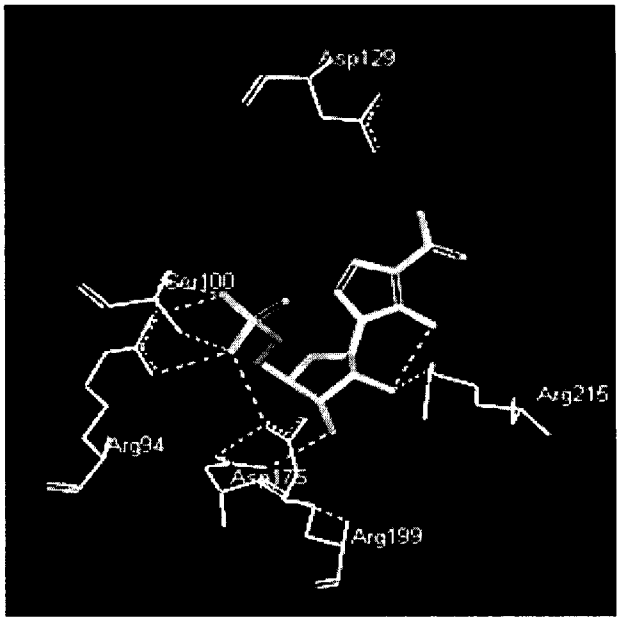


FIG. 1


Asp129
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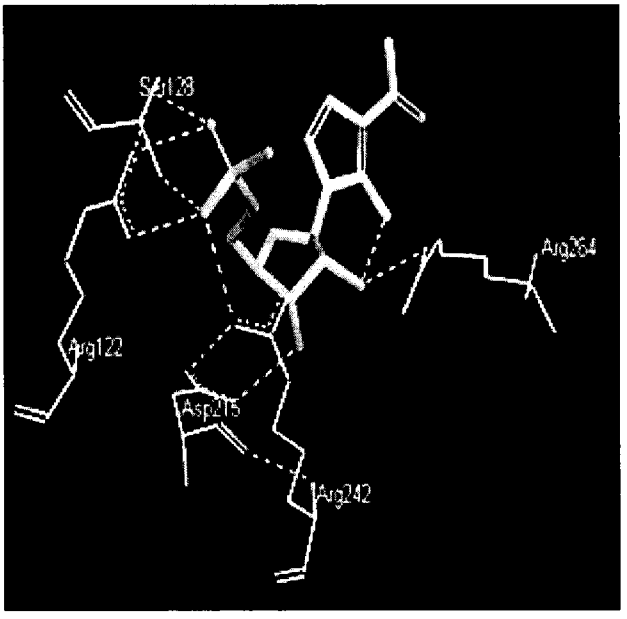
Arg94
Asn175
Arg199

FIG. 2A


Ser128
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Asp215
Arg242

FIG. 2B

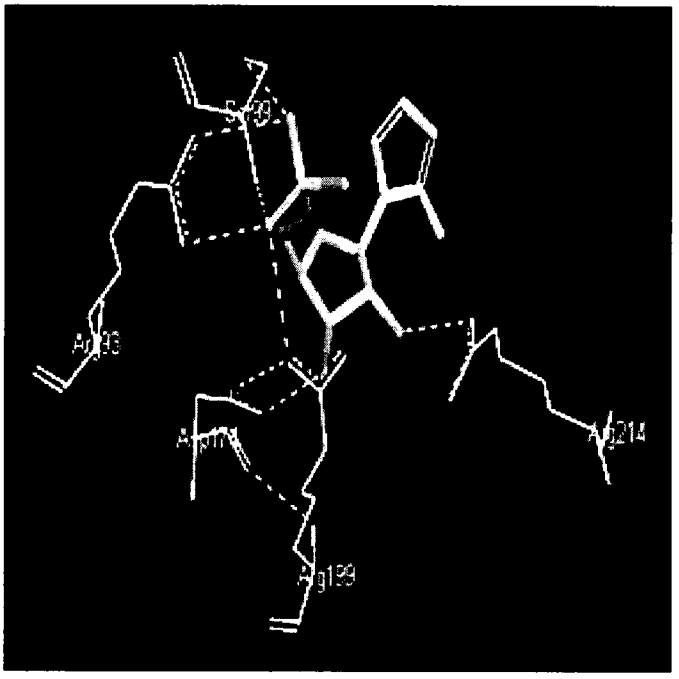
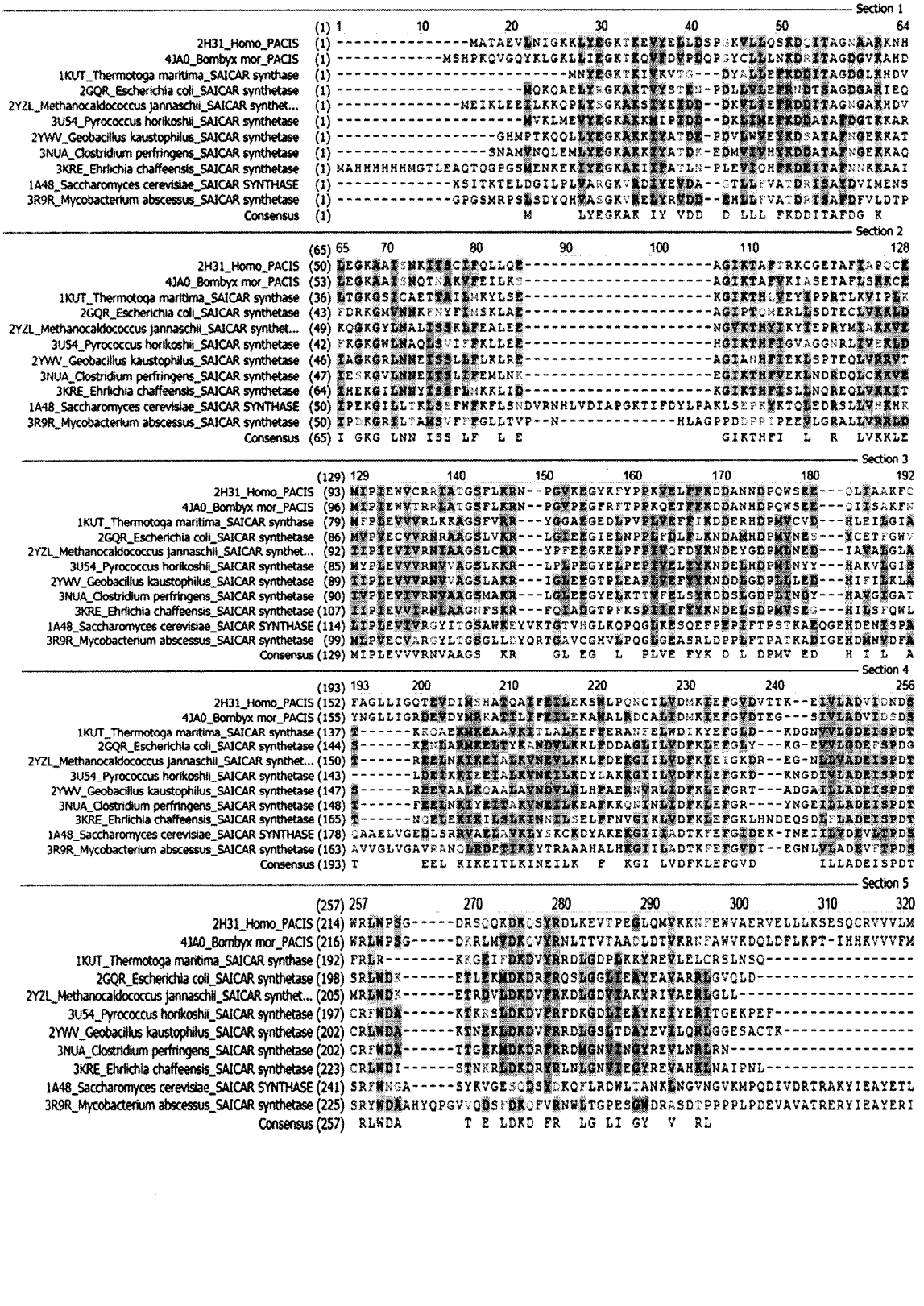
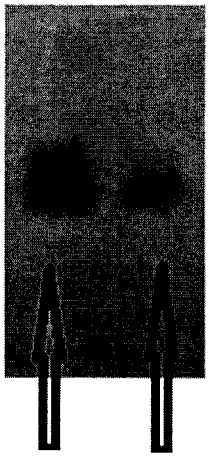


FIG. 2C


Section 1
Section 2
Section 3
Section 4
Section 5
2H31_Homo_PACIS
4JA0_Bombyx mor_PACIS
1KUT_Thermotoga maritima_SAICAR synthase
2GQR_Escherichia coli_SAICAR synthetase
2YZL_Methanocaldococcus jannaschii_SAICAR synthet...
3U54_Pyrococcus horikoshii_SAICAR synthetase
2YWV_Geobacillus kaustophilus_SAICAR synthetase
3NUA_Clostridium perfringens_SAICAR synthetase
3KRE_Ehrlichia chaffeensis_SAICAR synthetase
1A48_Saccharomyces cerevisiae_SAICAR SYNTHASE
3R9R_Mycobacterium abscessus_SAICAR synthetase
Consensus



Control (no spermidine)

Experimental group (with spermidine)
(MYC is significantly inhibited)

FIG. 4

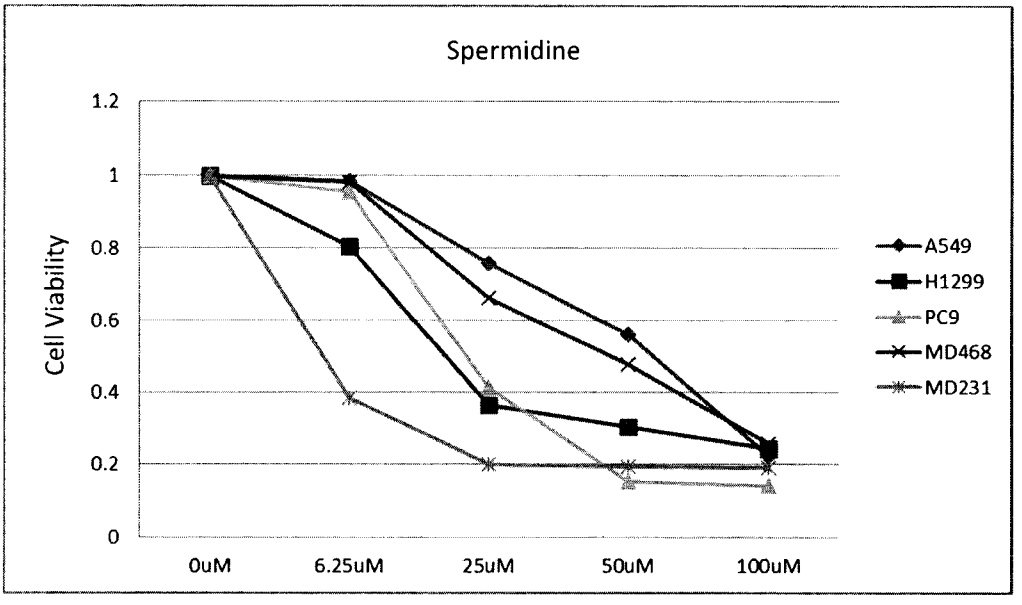


FIG. 5