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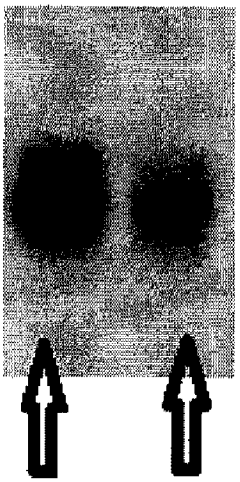
(54) Title: APPLICATIONS OF SPERMINE AND ITS DERIVATIVE IN PREPARATION OF ANTITUMOR DRUG



Control (no spermine)

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

(57) Abrégé/Abstract:
An application of spermine or its pharmaceutically acceptable derivative in preparation of an SAICAR synthetase activity interference agent or inhibitor. An application of spermine or its pharmaceutically acceptable derivative in preparation of an antitumor drug.

Abstract

Applications of spermine or its pharmaceutically acceptable derivative in preparation of an SAICAR synthetase activity interfering agent or inhibitor. Applications of spermine or its pharmaceutically acceptable derivative in preparation of antitumor drug.

APPLICATIONS OF SPERMINE AND ITS DERIVATIVE IN PREPARATION OF ANTITUMOR DRUG

TECHNICAL FIELD

The present disclosure relates to the use of a compound interfering with the activity of SAICAR synthetase, and particularly to the use of spermine and the derivatives thereof in the preparation of antitumor drug.

BACKGROUND ART

One important mark of cancer cells is metabolic reprogramming, includingincreased glucose uptake and oxygen-independent malolactic 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 modefor the correlationof the metabolic reprogramming of tumor cellswiththe 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 (NAD, NADP, FAD 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

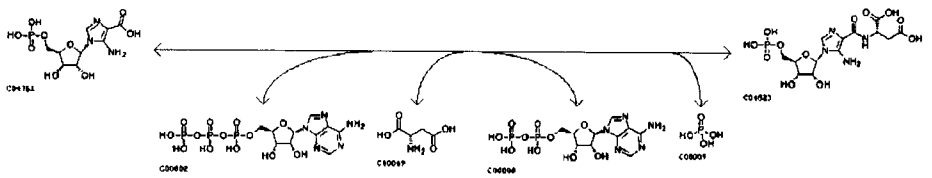
network. Purine synthesis comprises two synthetic pathways, i.e. *de novo* purine synthesis and salvage pathway.

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).*Adenylosuccinate lyase deficiency.*Mol Genet Metab 89, 19-31.Clamadieu, C., Cottin, X., Rousselle, C., and Claris, O.(2008).*Adenylosuccinate lyase 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 adenylosuccinate lyase 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* (*phosphoribosylaminoimidazole succinocarboxamidesynthetase /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 would 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



Therefore, tumors having abnormally high expression of PAICS are often accompanied by the accumulation of the 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.

Spermine (DrugBank ID: DB00127) is a polyamine-based compound containing two amino groups and two imino groups.Spermine is generated *in vivo* from putrescine (butanediamine) and S-adenosylmethionine through catalysis with various enzymes. Spermine and spermidine are bothpresent in bacteria and in most animal cells, and are important substances for promoting cell proliferation. Under acidic condition, it exhibits the characteristics of polycationic polyamines, and can bind with DNA in viruses and bacteria to make the DNA molecules more stable and flexible.It is also one of the necessary components in cell culture media. Spermine 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 spermine can promote the development of tumor cells and is a tumor promoter. Therefore, it is conductive to cancer-fightingby reducing the supply of spermine.

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SUMMARY OF THE INVENTION

An objective of the present disclosure is to provide use of spermine and derivatives thereof in the preparation of antitumor drugs.

The inventors, on the basis of existing data relating to the protein and small-molecule structures, performed calculation and analysis using software, and found that a compound with DrugBank ID DB00127 (general name: spermine) 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 cancer and bladder cancer, and especially be selected from acute lymphocytic leukemia, lung cancer, glioma, prostate cancer, and colorectal cancer which have thehigh expression of PAICS.

The meaning of"high expression" as used herein is well known in the art, and refers tothe expression which is significantly increasedas compared to that of normal tissues.

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 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 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, and acylated 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 CAIR and SAICAR synthetase in the crystal structure, 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 spermine on oncogene MYC.

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, 10BD, 10BG), *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), *Ehrlichia chaffeensis* (3KRE), *Geobacillus kaustophilus* (2YWV), as well as PAICS crystal structure data of *Homo sapiens* (2H31) and *Bombyx mori* (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 are Arg122, Ser128, ASP215, Arg242 and Arg264; the residues within CAIR 3Å in 2GQS are Arg94, Ser100, ASP129, ASP175, Arg199 and Arg215; and the residues within CAIR 3Å in 4FE2 are 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 would be not reliable. 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 DB00127 (general name: Spermine) has a Dock Score of 316.723, indicating that the compound spermine can effectively interact with PAICS, and influence the synthesis of SAICAR.

Experimentalresult data ofthe inhibition of spermine on PAICS activity

It is confirmed by further biochemical enzyme activity experiments and cell biology experiments that the compound spermine can inhibit the accumulation of SAICAR up to 71.1%. The accumulation of toxic compound SAICAR is reduced by inhibiting the activity of PAICS.

Experimentalresult data of theinhibition of spermine on oncogene MYC

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

Experimentalresult data of theinhibition of spermine on cancer cells

It is confirmed by further cell biology experiments that the compound spermine can effectively inhibit the growth of a lung cancer cell strain A549, a lung cancer cell strain H1299, a breast cancer cell strain MD468, and a breast cancer cell strain MD231 (the IC_{50} values after 48 hours of drug administration are shown in table below), the anti-cancer effect is very significant.

Cancer cell	IC50 (μM)
A549	117.317
H1299	25.157
MD468	38.027

MD231	3.552

The above calculation data and experimental data fully indicate that spermine 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 cancer and bladder cancer. The tumor may especially be acute lymphocytic leukemia, lung cancer, glioma, prostate cancer, and colorectal cancer which have high expression of PAICS.

The pharmaceutically acceptable derivatives of the above compound 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 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).

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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, and acylated 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 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 treating or relieving a tumor in a patient, wherein the tumor of the patient has been determined to have a high expression of phosphoribosyllaminoimidazole succinocarboxamide synthase / phosphoribosylaminoimidazole carboxylase PAICS,

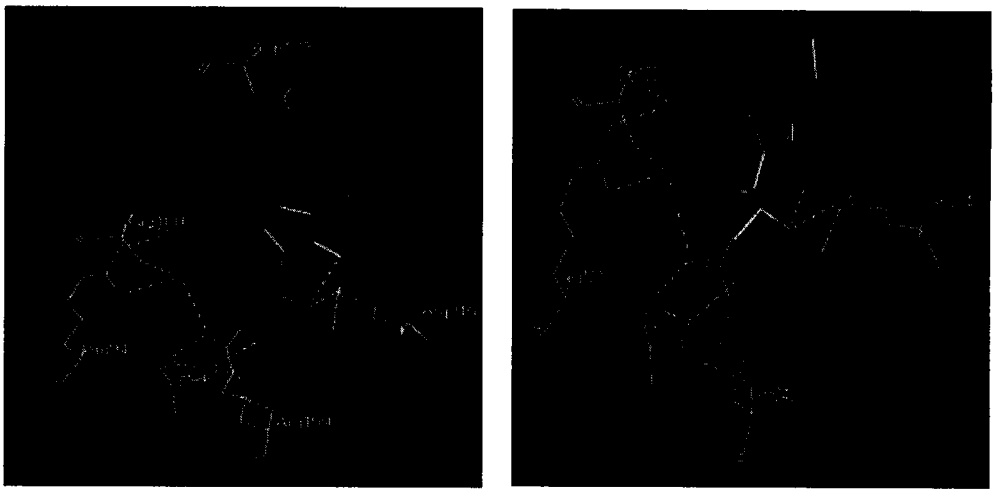
wherein the composition comprises spermine or a pharmaceutically acceptable salt thereof as an active ingredient; and,

a pharmaceutically or bromatologically acceptable excipient.

2. The pharmaceutical composition for use according to claim 1, 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, having high expression of PAICS.

Date Reçue/Date Received 2022-01-13

Fig. 1



(A) (B)

(C)

Fig. 2

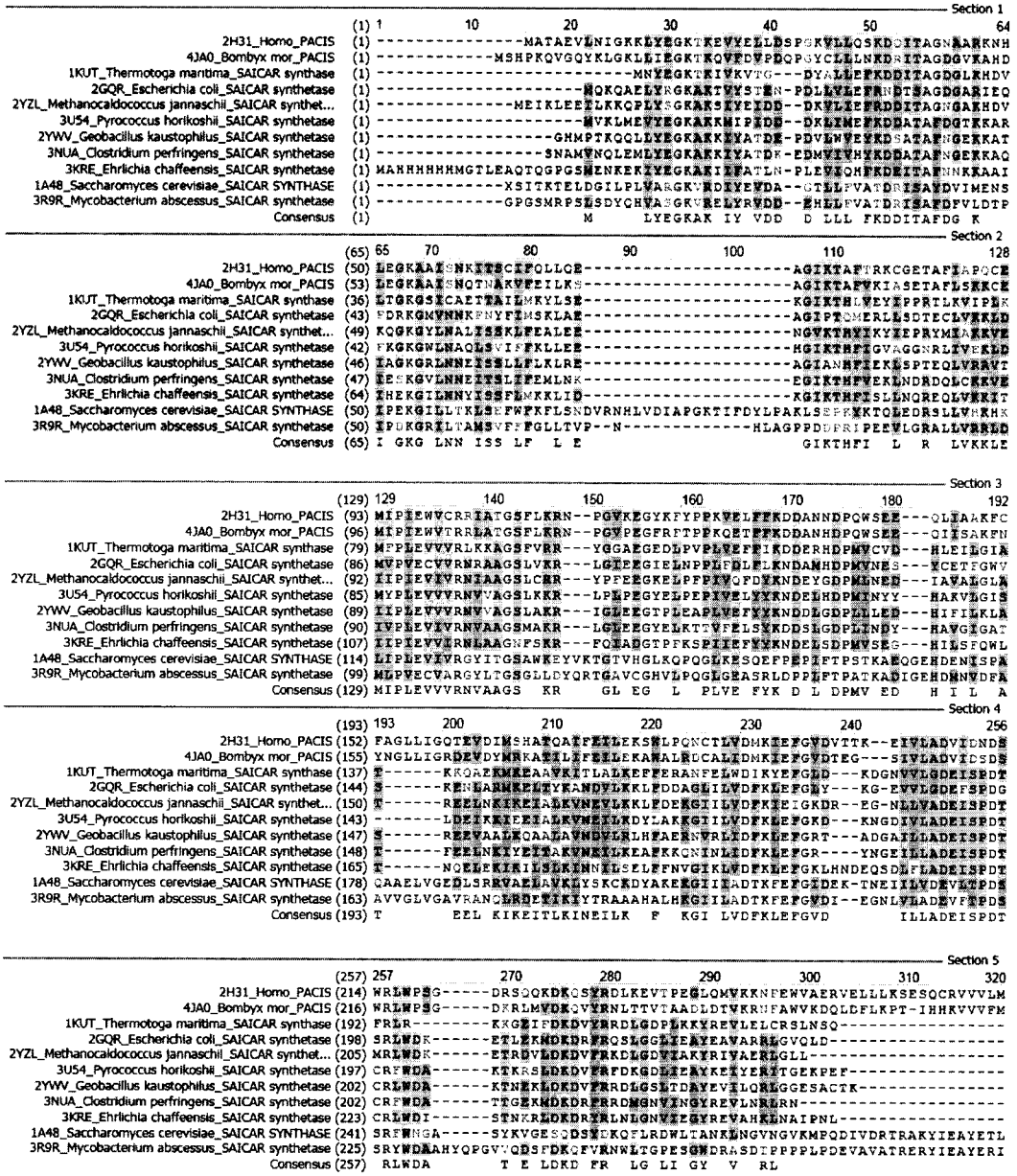
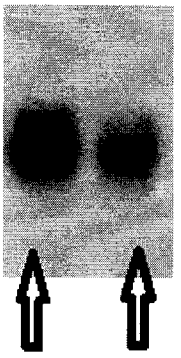

Section 1
Section 2
Section 3
Section 4
Section 5
2H31_Homo_PACIS
4JA0_Bombyx mor_PACIS
1KUT_Thermotoga maritima_SAICAR synthase
2GQR_Escherichia coli_SAICAR synthetase
2YZL_Methanocaldococcus jannaschii_SAICAR synthet...
3U54_Pyrococcus horikoshii_SAICAR synthetase
2YWV_Geobacillus kaustophilus_SAICAR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

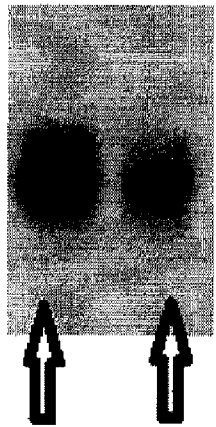
Fig. 3



Control (no spermine)

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

Fig. 4



Control (no spermine)

Experimental group (with spermine)
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