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<th>Modified Bacteria and their Uses thereof for the Treatment of Cancer or Tumor</th>
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Described herein is a method of treatment of cancer or tumor using a modified bacteria or composition comprising the modified bacteria. In certain embodiments, the method is in combination with other treatment. In certain embodiments, the treatment is chemotherapy, radiation therapy, gene therapy, surgery or a combination thereof. The method makes modified facultative anaerobic bacteria into a conditional obligate anaerobe. The modified bacteria are strictly hypoxia regulated and comprise an essential gene expressing cassette. The vectors of this method comprise the essential gene expressing cassette. Also described herein are therapeutic and prophylactic compositions comprising the modified bacteria. The therapeutic and prophylactic compositions contain a purified form of the modified bacteria, while in certain embodiments, they do not contain other strain of microorganisms. The modified bacteria grow within the solid tumor/cancer, retarding its growth and are rapidly eliminated from normal tissues. The solid tumor/cancer includes breast cancer, liver cancer or neuroblastoma.
Fig. 2A

```
1     GTAAAGC9CAA CCGATGGCGT ACCGCTGCGG G3TTTGGCGT TAACCACCCCT
51    AATCCACTCTT AATTGGGCGG GTCACTCTAC CGGAACCAC CGTGAACGCC
101   AACCTCTGGT CTCGACTACT CTATTACCT TATAGCTGAG AAGCTTGTCA
151   AAGTGAAATA TTCTTGGTTG CAGGGATATAA AGTGAACCGGA CGCAATATT
201   GTCTTTCCTT GCTTATTAA TATGTTGCTA CGAAAGA
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Fig. 2B

```
1     ATGAAAAATG TTGGTTTAT CGCGCTGCGG G3AATGGCGT GCTCTGTGCT
51    CATGCAACGC ATGGTAGAGG AGCGCGATTG CGACGCTATT CGCCCTGTTT
101   TCTTTTCATC CTCCCCAGTGT G3CAAGCGGCG CGCCACCTCT CGCGCACCC
151   TCCAGCGGCA CGTACAGAGA CGGTTTGTAT CGTGGATGCG TAAAGCGCT
201   CGATATCATCT GTGACTGTGCG AGGGCGGGAGA TTATACCAAC GAAATTATCT
251   CAAAGCTGCG CGAAAGCGGA TGCGCAAAGTT ACTGGAATTG CGCGCTTCTC
301   AGCGCGCAGA TGAAGATAGTA TGCCATTATT ATTCTGCGCC GCGTGAACCA
351   GGAAGTGATT AGCGCGCGAC TGAACAATGG CGTGAAGCAG TTTGTTGGCG
401   GTGACTGTAC CGTTAGCGTG ATGTGAATGT CGCGTGCGCG GCTCCTTGGC
451   CATATCTGCG TTGAGGTGCT ATCCCGTCGG ACCTATCAGG CGGCGCTCGC
501   CGCGGCGGCG CGCCGATATGC GGACGCTGGT AACCAGAAATG GGGCAGTTGT
551   ATGCGGCTATG CGCGGTGAAA CTGGCGACGC CGTCTTCCGC AATTCTGAT
601   ATTGAAAGCA AGTGTAGGCG ATTGACCCGC AGCGGCGACG TGCCGTTGCA
651   TAATCTTGCG GTACCGCTGGC GGCGGAACTC GATCCCGTCG ATCCGACCCAA
701   AGCTTGATAA CGCGCAAGAGC CGGGAAGAGG GGAAAGGCAG GCCGGAACC
751   AACAAGATCC TCAACTCTGC CTCTTGAGAC CGCGGTGATT GCTGTTCGCG
801   GGCGCGCGGC CGCTGGCGCT GTACAGCCGA GGGTTGTCGA AATACGGAA
851   AAAAGAGGTT ATCCATTGCG AGCGTGGAAG AATCCTCGCG GCCGACAAAT
901   CGTGGCGGCA AAATGGGCGC GAGAAGCTGTC GATACTACTA TGCGCGAATT
951   AACCCCGCGC CGCGGAGCCC CGACGGTGAC TACCGCGGTT GCTCCGCGCC
1001  GTAAGCTGAA CATGGGGCGCA GACTTCTGGT CGCGGTTTAC GCTAGCGAC
1051  CAGTTGGTAT GGGGCGGCGG CGAAGCGCGT CGTCAATGCA TGCGCGAGTT
1101  GGCCTAG
```
Fig. 2C

1 MKNVGFIGWR QMVG5VLMQR MVEERDFDAI RPVFSTSSQF QQAAPTFGDT
51 STGLQDAFD LDALKALDII VTCQGDDYTN EIYPKLR5EG WQGYW4DAA5
101 TLRRKDAAII ILDPVNGQDI VTDGLNNGVKT FVGGNCTVSL MLMSLGGLFA
151 HNLVDWVSEVA TVQAASCGGA RHRRELLTQM GQLYGHVAD5 LAPTSSAILD
201 IERSKVTLTR S3ELPVDNFG VPLAGSLIPW ID5QLQDQS RESWKGQAET
251 NKILNTASVI PVDGLCVRVG ALRCHSQAFT I5KLKKEVS5P TVEELLA4HN
301 PMAKVVFNPDR DTIMRELTPA AVENTLTPFV GRLRKLNGP EFLS4FTVGD
351 QLLWGAAEPL RRMLQRQLA–

Fig. 2D

1 ACGAAAAAGTA CGGCATTGAT AATCATTTC AATATCATT AATTAACATAT
51 AATGAACCAAA
Fig. 3
Fig. 4A

FNR [2Fe-2S]

+O₂
Inactive

With DAP, alive;
Without DAP, Dead

Active

Fig. 4B

FNR [4Fe-4S]

−O₂
Active

With or without DAP, alive;
inactive
Fig. 5
Fig. 6
Fig. 7
Fig. 10
Fig. 11
Fig. 14A
Fig. 14B

Fig. 14C
Figs. 16A-D
Figs. 19A-F
Figs. 21A-C
Figs. 21D-E
MODIFIED BACTERIA AND THEIR USES THEREOF FOR THE TREATMENT OF CANCER OR TUMOR

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit of U.S. provisional patent application Ser. No. 61/687,975, filed May 4, 2012, which is hereby incorporated by reference in its entirety.

SEQUENCE LISTING

[0002] The instant application contains a Sequence Listing which has been submitted in ASCII format via EFS-Web and is hereby incorporated by reference in its entirety. Said ASCII copy, created on Apr. 30, 2013, is named Sequence_Listing_002893-US1.txt and is 10,182 bytes in size.

1. INTRODUCTION

[0003] Described herein is a method of treatment of cancer or tumor using a modified bacteria or composition comprising the modified bacteria. In certain embodiments, the method of treatment of cancer or tumor is in combination with other cancer or tumor treatment. In certain embodiments, the cancer or tumor treatment is chemotherapy, radiation therapy, gene therapy, surgery or a combination thereof. Described herein is a method of making modified facultative anaerobic bacteria into a conditional obligate anaerobe. In one aspect, the modified bacteria are strictly hypoxia regulated and comprise an essential gene expressing cassette. Described herein are vectors, cells comprising the vectors comprising the essential gene expressing cassette. Also described herein are therapeutic and prophylactic compositions comprising the modified bacteria. In certain embodiments, the therapeutic and prophylactic compositions contain a purified form of the modified bacteria. In certain embodiments, the therapeutic and prophylactic compositions do not contain other strains of microorganisms. In one aspect, the modified bacteria grow within a tumor/cancer, retarding its growth. In one aspect, the tumor/cancer is a solid tumor/cancer. In one aspect, the modified bacteria are rapidly eliminated from normal tissues. In certain embodiments, the tumor/cancer includes, but is not limited to, breast cancer, liver cancer or neuroblastoma.

2. BACKGROUND

[0004] Cancer is one of the most deadly diseases in the present world. Facing cancer, most people believe surgery, chemotherapy or radiation therapy is the only possible solution. However, not all cancer patients are suitable for surgery, and cancer metastasis may cause the failure of surgery treatment. The chemotherapy or radiation therapy may lead to large damage of normal organs and less effect on cancer niche. Furthermore, hypoxic tumor cells may demonstrate an inhibition of cell cycle progression and proliferation, and hence may be relatively resistant to many antitumor drugs that target rapidly dividing cells. Thus, in solid tumors, hypoxic regions create a further problem as they are resistant to many treatments [1] and are linked to more malignant phenotypes [2].

[0005] Intentional use of bacteria in cancer treatment can be dated to the late 19th century with even earlier anecdotal reports of bacterial efficacy in treating cancer [3, 10, 11]. The first reported deliberate attempt at using bacteria (Streptococcus pyogenes) to treat an inoperable sarcoma also demonstrated the inherent danger of the technique. Whilst the tumor and lymph nodes reduced appreciably, the patient died of infection within 9 days of treatment [3, 10, 11]. On the other hand, targeted cancer therapy, gene therapy and cancer vaccine are all based on the transfection technique. The most critical issues associated with these therapeutic strategies are the safety of vectors. Viral vectors are most widely used delivery vectors, however, they are not easy to be eliminated, potentially tumorigenic with limited capacity. Accordingly, non-viral vectors with larger capacity and safe manipulation, such as bacterial vectors, are a promising approach to develop new delivery systems.

[0006] Consequently, much recent work on bacterial therapies for cancer has focused on non-pathogenic strains or the need to attenuate bacteria for use in model systems and humans. Bifidobacteria are non-pathogenic obligate anaerobes and have been successfully used to target tumors and as a therapeutic vectors but do not appear to have an oncolytic effect [8, 12-14].

3. SUMMARY

[0007] Described herein is a modified bacteria comprising a strictly hypoxia regulated essential gene expressing cassette. Also described herein is a composition comprising the modified bacteria. Also described herein are therapeutic and prophylactic compositions comprising the modified bacteria. In certain embodiments, the therapeutic and prophylactic compositions contain a purified form of the modified bacteria. In certain embodiments, the therapeutic and prophylactic compositions do not contain other strains of microorganisms.

[0008] Provided herein is a strictly hypoxia regulated cassette comprising a forward anaerobic inducible promoter, an essential gene and a reverse aerobic promoter.

[0009] Described herein are vectors, cells comprising the vectors. In certain embodiments, the vectors comprise the essential gene expressing cassette. Described herein is a vector comprising a hypoxia conditioned promoter operatively linked to an essential gene. In one embodiment, the hypoxia conditioned promoter comprises an inducer binding site. In one embodiment, the vector further comprises an antisense promoter that is negatively regulated by the inducer.

[0010] Described herein is a method of making the modified bacteria. Also described herein is a method of making modified facultative anaerobic bacteria into a conditional obligate anaerobe. In one aspect, the modified bacteria are strictly hypoxia regulated and comprise an essential gene expressing cassette.

[0011] Also described herein is a method of treatment of cancer using a modified bacteria or a composition comprising the modified bacteria. The method inhibits and reduces the growth of a tumor cancer when administered in vivo. In certain embodiments, the method of treatment of cancer is in combination with other cancer treatment. In certain embodiments, the cancer or tumor treatment is chemotherapy, radiation therapy, gene therapy, surgery or a combination thereof. In one aspect, the modified bacteria grow within the solid tumor/cancer, retarding its growth. In one aspect, the modified bacteria are rapidly eliminated from normal tissues. In certain embodiments, the solid tumor/cancer includes, but is not limited to, breast cancer, liver cancer or neuroblastoma.

[0012] Also described herein is a kit comprising the modified bacteria and a pharmaceutically acceptable carrier.
[0013] Described herein is a method to provide an obligate anaerobe from a facultative anaerobe. In another embodiment, the facultative anaerobic is a Gram-negative bacteria. In certain embodiments, the facultative anaerobic includes, but not limited to Salmonella typhimurium. In certain embodiments, the modified bacteria are effective in anti-tumor therapy. In certain embodiment, the essential gene is, for example, a gene for aspartate-semialdehyde dehydrogenase ("asd"). In certain embodiments, asd is operatively linked and is under the control of a hypoxia-conditioned promoter. In certain embodiments, the normal functions of the bacteria are not compromised by the deletion or mutation of any of its genes.

[0014] In one embodiment, the modified bacteria are YB1. Comparison of the new strain YB1 with previously studied tumor-targeting Salmonella strain VNP20099 shows that YB1 is more effective in both targeting and repressing tumor growth than VNP20099. Furthermore, YB1 was eliminated from normal tissues much faster than VNP20099 in breast cancer animal model. In one embodiment, the modified bacteria are not VNP20099.

[0015] In one embodiment, the modified bacteria are not viable in normal tissues. In one embodiment, the modified bacteria are made by placing an essential gene, asd, under the control of a hypoxia-induced promoter. In one embodiment, the essential gene is asd or diaminopimelic acid ("dapA"). The asd gene of Salmonella encodes an enzyme essential for the synthesis of diaminopimelic acid (DAP), which is an essential component of the bacterial cell wall and not present in mammalian systems [7]. In one embodiment, with asd expressed only in hypoxic conditions the bacteria are able to grow readily under hypoxia, but will lyse under normal growth conditions. Thus in certain embodiments, facultative anaerobic Gram-negative bacteria, including, Salmonella typhi, can be converted from a facultative to an "obligate" anaerobe, rendering it safe in normal tissues. In certain embodiments, the modified bacteria are Salmonella typhimurium, Salmonella choleraesuis, Salmonella enteritidis and S. typhimurium, Escherichia coli, Escherichia coli K-12, Escherichia coli O157:H7, Shigella, Shigella dysenteriae, Shigella flexneri, Shigella boydii, Shigella sonnei, Yersinia, Yersinia pestis, Yersinia pseudotuberculosis and Yersina enterocolitica.

[0016] In one embodiment, a cassette described herein is regulated by fumarate and nitrate reduction gene ("fan") which are involved in the switch between aerobic and anaerobic growth [42]. Promoters containing FNR binding sites are activated under hypoxia [43]. Provided herein, in an embodiment, the pepT promoter created a gene therapy vector only expressed in hypoxic regions [43]. In certain embodiments, the pepT promoter (PpepT) was used to drive expression of asd, conditional on hypoxia, in a modified Salmonella SL7207 (YB-pw), limiting the bacterial viability to hypoxic regions. In an embodiment, the asd gene in the modified bacteria was replaced with a PpepT-asd construct (FIG. 1B). In certain embodiment, the essential gene is under the control of L-ascorbate peroxidase II ("lasB") or formate dehydrogenase-II ("fdhB") promoter. However, in certain embodiment, the modified bacteria are still able to grow under normal oxygen levels. In one embodiment, to prevent leakage from the pepT promoter, an antisense promoter of the superoxide dismutase ("sodA") gene (PsodA), which is negatively regulated by FNR [44], was added to the PpepT-asd construct to make the PpepT-asd-sodA (FIG. 1A), which then further constructed strain YB1. This effectively inhibited the growth of Salmonella as shown in FIG. 5-7 where YB1 could only grow in the absence of DAP under anaerobic but not under aerobic conditions. An alternate construct using the ansB promoter (YB-EW) is ineffective under anaerobic conditions. In the absence of DAP, YB1 was the only strain that had the combination of growth under anaerobic but not aerobic conditions. A detailed titration of oxygen level and bacterial concentration showed that, in the absence of DAP, YB1 was only viable at oxygen levels below 0.5% (FIG. 7). Unlike SL7207, YB1 only infiltrated the MDA-MB-231 breast cancer cells under anaerobic conditions. However, it was more effective at inducing apoptosis or cell death, possibly due to the anaerobic expression of asd being stronger under the hypoxia conditioned promoter as compared to the wild type one (FIG. 4).

[0017] Certain embodiments shows SL7207, YB1 and an attenuated Salmonella strain VNP20099 were able to infiltrate MDA-MB-231 tumors induced in nude mice, as evidenced by the considerable number of bacteria found in the tumor and the considerable tumor damage observed. Although quiescent YB1 cells appear to persist briefly in aerobic tissues in the absence of DAP [45], YB1 was effectively cleared from normal tissues. By 3 days post infection, bacteria were barely detectable in liver. VNP20099 was less effectively cleared from normal tissues than YB1 and less effective at reducing tumor size. SL7207, despite being an attenuated vaccine strain, had a similar effect on normal and tumor cells and killed all mice by 11 days post infection with substantial bacterial induced liver destruction apparent. While SL7207 might not affect immune-competent mice, the conversion of SL7207 to the "obligate" anaerobic YB1 prevented bacterial killing of the mice while maintaining and enhancing tumor killing ability.

[0018] Described herein is an examination of the effect of YB1 in tumors. The examination showed that its design as an "obligate" anaerobe was effective in that it was tightly confined to the hypoxic regions of tumors and kept distant from blood vessels. As bacteria are expected to induce a host immune response, neutrophils were found in the YB1 infected tumors. In one embodiment, YB1 and neutrophils aligned against each other with neutrophils as a barrier against further bacterial spread. In one embodiment, YB1 enhances tumor killing by strongly attracting neutrophils to the tumor.

[0019] In one embodiment, described herein is the use of combination therapy with YB1 and chemotherapy. In one embodiment, the chemotherapy includes treatment with, but not limited to 5-FU which increase the tumor inhibition ability. 5-FU target rapidly dividing cells like cancer cells by blocking the action of thymidylate synthase [46]. When compared with untreated mice, YB1 considerably retarded tumor growth with an effectiveness greater than that of the drug 5-FU alone. In one embodiment, YB1 and 5-FU were more effective. SL7207 was too toxic and was lethal to the mice before effects on tumor growth could be observed (FIG. 13).

[0020] Described herein is an improved anticancer method than those utilize Salmonella strain VNP20009. VNP20009 was derived from strain YS72 [47], which was generated by nitrosoguanidine and UV irradiation induced random mutations from wild type Salmonella typhimurium 14028 [20]. This random mutagenesis strategy produces safe auxotrophic strains with compromised tumor targeting or killing abilities. VNP20009 in phase I clinical, in which inefficiency of tumor targeting and repressing was observed [48]. If some unknown
functional genes of Salmonella were mutated in the process of attenuation, the VNP20009 might be over-attenuated [49]. On the contrary, strain SL7207 as the predecessor of YB1 was generated by aro transposon insertion [28]. The precise modification of Salmonella strain SL7207, by placing an essential gene under a hypoxia conditioned promoter, as performed in the present invention has successfully converted the bacterium to an “obligate” anaerobe, thereby removing the lethal toxicity of the host strain while maintaining its tumor targeting and enhancing its tumor killing abilities than VNP20009 (FIG. 9C & FIG. 13D). Furthermore, comparing with VNP20009, YB1 showed higher tumor habitating preference while the engineered YB1 strain also showed quicker eradication in normal organs (FIG. 9C). By resulting in less toxicity and better therapeutic performance, this novel strategy provides an alternative to conventional attenuation techniques, which may compromise bacterial tumor killing effect.

[0021] In one embodiment, described herein is a method to make the modified bacteria. Similar method may be used to make the modified bacteria of various strains. In one embodiment, the modified bacteria are Strain YB1 which is conditional obligate and facultative anaerobe. First, YB1 has specific tumor targeting ability as C. sporogenes, but it does not always need anaerobic culture for condition. Simple DAP supplement could restore YB1 as functional as normal facultative anaerobic bacteria. Second, YB1 as a strain of Salmonella typhimurium can share the same replication origin of plasmids with E. coli, it’s easier and more convenient to construct plasmid-based drug delivery vector and to control the copy number of the vector in cancer therapy. While the ease of modifying Chlostridia to produce gene therapy vectors [17, 18] has improved [50], Salmonella can be readily transformed using long-established techniques and YB1 could be developed similarly. YB1-like bacteria have the advantages of an obligate anaerobic bacterium while maintaining the chemotherapeutic properties [5, 22] and ability to target metastasis [25-27] of Salmonella.

[0022] Conditioning Salmonella growth on hypoxia provides an alternative to conventional attenuation techniques, which requires a mutation of the bacteria to compromise some normal function. The modified “obligate” anaerobe YB1 represents a new direction in producing bacterial therapeutic agents for cancer.

4. BRIEF DESCRIPTION OF THE FIGURES

[0023] The patent or application file contains at least one drawing executed in color. Copies of this patent or application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

[0024] FIGS. 1A-C. (A) the construct (pYB1) of strictly hypoxia regulated an essential gene expressing cassette, which contained the sense promoter PpepT, asd gene, and the antisense promoter Psoda; (B) the construct (pYB1-pw) without the antisense promoter Psoda; and (C) the construct (pYB1-pw) with the different promoter PansB.

[0025] FIGS. 2A-D. (A) the DNA sequence of promoter PpepT (SEQ ID NO: 18); (B) the DNA sequence of asd gene (SEQ ID NO: 19); (C) the protein sequence of Asd protein (SEQ ID NO: 20); and (D) the DNA sequence of promoter Psoda (SEQ ID NO: 21).

[0026] FIG. 3. The recombination engineering strategy replaces the original asd gene from the chromosome of bacteria with the strictly hypoxia regulated and chromosome-based an essential gene expressing cassette.

[0027] FIGS. 4A-B. The situation when YB1 is facing the environment with O₂ (A) and without O₂ (B).

[0028] FIGS. 5A-D. Growth rate of various strains (10⁴ bacteria/ml) under aerobic or anaerobic conditions in LB broth without DAP (mean±sd, each time point represents three individual experiments). (C, D) as in (A, B) but with DAP.

[0029] FIG. 6. To test asd expression in response to oxygen, strains YB1-myc-EW, YB1-myc-PW, and YB1 were cultured under aerobic (+O₂) or anaerobic (-O₂) conditions for 24 hours at 37°C. DAP was added to prevent cell lysis under aerobic conditions. Bacterial cell number was quantified by OD₆₅₀ measurement and total protein was extracted from those bacteria respectively.

[0030] FIG. 7. Different mutant strains at serial dilutions under decreasing oxygen levels were cultured for 24 hours and bacterial growth was observed. Columns: 1 SL7207; 2 YB-asd; 3 YB1; 4 YB-pw; 5 YB-ew. (Three independent experiments were performed.)

[0031] FIGS. 8A-C. YB1 and SL7207 in breast cancer cells (A) In vitro cultured breast cancer cells (MBA-MB-231) were exposed to YB1 and SL7207 (1: 500-1000) separately under anaerobic (O₂<0.5%: YB1-O₂, SL7207-O₂) or aerobic (O₂>21%: YB1+O₂, SL7207+O₂) conditions. Two hours post-incubation, breast cancer cells were washed and fresh medium containing gentamycin (50 μg/ml) was added to remove extracellular bacteria. 24–48 hours later, breast cancer cells were collected, stained using an anti-Salmonella antibody (red) and phalloidin to indicate cancer cells (green) and observed by confocal microscopy. Merged and enlarged images are given. (B, C) Apoptosis and death rate of cancer cells induced by Salmonella under anaerobic conditions were detected by annexin-V/PI staining and measured by flow cytometry. *, P<0.05.

[0032] FIGS. 9A-C. CFU test of YB1, SL7207, and VNP20009 in breast tumor bearing nude mice. Nude mice with an MBA-MB-231 tumor received temporal vein injections of YB1, SL7207 or VNP20009. Mice were euthanized at the indicated time points and blood, heart, kidney, liver, lung, lymph node, spleen and tumor tissues were collected and homogenized and a bacterial accumulation evaluated. In SL7207 (A) YB1 (B) or VNP20009 (C) treated mice, CFU counts per gram of most normal organs and tumor (red line) are shown over time (mean±sd, each time point represents three individual experiments with 2 mice for each experiment); *, tumor group vs. all other groups P<0.05; **P<0.01.

[0033] FIGS. 10 (A-B). Paraffin section test of YB1 and SL7207 in tumor and liver. The distribution of Salmonella in tumor (A) and liver (B) of breast tumor bearing mice over time was demonstrated in tissue paraffin sections by immunostaining. (Arrows: Salmonella).

[0034] FIG. 11. YB1 colonization of the hypoxic region. Y31 and PBS treated tumor bearing mice were i.p. injected with hypoxyprobe-1 before being sacrificed. Tumor samples were removed, prepared and visualized with anti-Salmonella or anti-hydroxypropane-1 antibodies as noted in Materials and Methods. The transverse sections show an overview of the hypoxic area and YB1 distribution in the tumor. PBS treated tumor-bearing mice were used as a control.

[0035] FIGS. 12 (A-C). Confinement of YB1 in the tumor. (A)YB1 and the hypoxic region are indicated by staining with anti-Salmonella (green) and anti-hypoxyprobe (red) antibod-
ies, respectively. DNA is indicated by DAPI staining (purple); H: hypoxic area. V: viable area. (B) Blood vessels in the tumor are shown by an anti-CD31 antibody (red, arrows). (C) Immunocytes were detected with an anti-Gr-1 antibody (red).

**0036** FIGS. 13 (A-D). Repression of tumor growth by *Salmonella* strains. (A) Tumor volume (starting size about 500-550 mm³) in mice injected with YBI1, SL7207 or PBS (n=10, mean±sd). SL7207 treated mice died by day 11. *, YBI1 group vs. PBS group, P<0.05; **, P<0.001. (B) Survival chart for tumor free and tumor bearing mice treated with YBI1, SL7207, YB-asd or PBS, respectively (n=10 each). (C) Tumor bearing mice were treated with YBI1 or PBS (n=24). After three days, 5-FU was injected i.p. (60 mg/kg) to half the mice of each group (n=12) and repeated every three to four days for 2 weeks. *, YBI1+5-FU group vs. PBS group and 5-FU group, P<0.05; **, P<0.001; #, YBI1+5-FU group vs. YBI1 group, P<0.05; ##, P<0.01; ###, P<0.001. (D) Comparison of strain YBI1 and VNP2009 for anti-tumor effect. Tumor volume (starting size about 360 mm³) in mice after treatment with VNP2009, YBI1, or PBS, respectively (n=6, mean±sd). *, YBI1 group vs. VNP2009 group, P<0.05; **, P<0.01.

**0037** FIG. 14A. Monitoring in situ liver tumor growth with YBI1 treatment. After two weeks of Luciferase labeled MHCC97L tumor seeds were implanted into the left liver lobes of healthy nude mice group, S6+07 CFU YBI1 was i.v. administered through tail vein. The tumor growth was monitored by Xenogen IVIS 100 at different time points after YBI1 treatment on day 0, day 10, week 2, and week 3. The upper panel is PBS treatment group. The lower panel is YBI1 treatment group. Each mouse was i.p. with 1000 μg D-Luciferin before imaging.

**0038** FIGS. 14B-C. Comparison of in situ tumor growth by histology and lung metastasis by live imaging with and without YBI1 treatment in liver cancer nude mice model 3 weeks after tumor implantation. (B), comparison of tumor size in live tissues by histology; (C), examination of lung metastasis of MHCC97L tumor cells. The colorful signal indicated lung metastasis. The upper panel is PBS control group. The lower panel is YBI1 treatment.

**0039** FIGS. 15A-C ‘Window chamber’ animal model. A, nude mice for dorsal window chamber in the surgery; B, Window chamber model after surgery; C, Blood vessels distribution of window chamber under stereo microscopy.

**0040** FIGS. 16A-D ‘Window Chamber’ imaging for tumor progression under stereo microscopy. A, Transmission bright field imaging of blood vessels; B, Fluorescence imaging of tumor after three days implantation; C, D Enlarged image of blood vessels and tumor cells was found around vessels.

**0041** FIGS. 17A-D Observation the effect of YBI1 treatment. A, Time-lapse track tumor regression caused by YBI1 treatment from 30 mins to 5 days; B, In vivo image of alive cancer cells without YBI1 treatment; C, D, Apoptosis of cancer cells induced by YBI1 after 12 (C) and 36 hrs (D), signals are tTOMato labeled MDA-MB-231 cancer cells. Arrows indicate YBI1 distributions. Scale bars, 100 μm.

**0042** FIGS. 18A-D Tumor infiltrating immune cells at different time points. A, tumor infiltrating immune cells; B, Ly6G+ neutrophils; C, CD19+ B lymphocytes; D, CD49b+ natural killer cells (NKs).

**0043** FIGS. 19A-F Paraffin-embedded biopsy of the distributions of YBI1 and immune cells within tumor. A, B, C & D: paraffin tissue sections stained with anti-Ly6G antibody (shown as dark grey); Ly6G: a marker of neutrophils, E & F: tissue sections stained with anti-Salmonella antibody (shown as dark grey). Dash lines indicate tumor necrotic area.

**0044** FIG. 20 Cell proliferation assay for Hela cells with or without YBI1 treatment. Cells (1x10^5) were seeded in a 96 well plate and grew for overnight. After a 2 h-incubation of YBI1 (M.O.I=1:200), cells were subsequently cultured for 24, 48, 72 and 96 hrs and MTT assay was performed. Absorbance was measured at 570 nm.

**0045** FIGS. 21A-E YBI1 invasion assay with different cancer cell lines under anaerobic condition. Cancer cells of Lung cancer A549 (A), Colon cancer Caco-2 (B), Ovarian Cancer ov433 (C), Myeloma NCI-D (D), and Neuroblastoma SH-SYSY (E) were co-culture with YBI1 (M.O.I=1:200) for 1 hr, washed by PBS for three times, and further cultured for 24 hrs under anaerobic condition. Signals are indicating intracellular YBI1.

**DETAILED DESCRIPTION**

**0046** Since *Salmonella* is closely related to the *Escherichia* genus and has broad host-range, its genomic information is clear and share many common features with *E. coli*. Comparing with gram-positive bacteria (e.g. *Clostridium*), *Salmonella* are easy for genetic manipulation, since it has thin membrane, sensitive to drug selection. It survives and proliferates within cells; therefore it can deliver genetic material (DNA, mRNA, microRNA etc.) into the cytoplasm with interrupt the nucleus. Most important, transfection with bacterial vector can avoid (random) genomic integration. Thus, it may directly deliver ectopic miRNA into host cells and utilize translation machinery of host cell to synthesize the corresponding exogenous proteins. On the other hand, since it is facultative anaerobic, it is easy to culture it in vitro and then send them to target hypoxic region within tumors. Thus, *Salmonella* can serve as both bacterial “weapon” and “vector” in research and medication. Moreover, attenuated *Salmonella* has been proved to be safe in human for years.

**0047** Anaerobic bacteria provide an important treatment opportunity in cancer therapy due to their ability to target the hypoxic region of solid tumors that is resistant to conventional treatment [1, 3]. If *Salmonella*, a facultative anaerobic bacteria, is to be a successful treatment agent in anti-cancer therapy, bacterial virulence in the host needs to be addressed [11]. In most cases attenuated forms are created and used as test therapeutic agents [24, 29, 34, 40]. However, the mutations required to attenuate a bacterium might also compromise its tumor targeting and killing ability. This was suggested as a possible reason for the poor performance of VNP2009 in clinical trials [11]. Recently, a systematic study of *Salmonella* mutants [41] partially addressed this issue by identifying several attenuated mutant bacteria with either mild or moderate reductions in tumor fitness. Tumor killing by these mutants could not be examined [41].

**0048** In one embodiment, described herein is a method in converting anaerobic bacteria into conditioned “obligate” anaerobe. In one aspect, the method is strictly hypoxic regulated and comprising transforming bacteria with an essential gene expressing cassette. In one aspect, the method comprises facultative anaerobic Gram-negative bacteria, including but not limited to *S. typhimurium*. In normal tissues under aerobic conditions, an essential gene and is not expressed, dianimonopimelic acid (DAP) is not synthesized and the bacteria will lyse during growth unless DAP is supplied by the environment. In tumor bearing nude mice, the modified bac-
The original Salmonella strain was lethal to the mice. In contrast, several attenuated Salmonella strains have been developed for tumor targeting studies. SL2707, which has a defect in the araA gene and is a derivative of similar attenuated strains [28], has been used by several groups [29-33], although it can affect the health of immuno-compromised mice [29, 33]. Deletions in puf and msbB gave rise to VNP20009 [21, 34] which has been used for gene-targeted pro-drug therapy [35] and tested for oral delivery [36] and in clinical trials [37, 38]. Strain A1 [39] and its derivative A1-R [24] are leucine-arginine auxotrophs and A1-R targeted a metastases model [26]. Defects in guanosine 3’-diphosphate-3’-diphosphate synthesis attenuated Salmonella (strain AppCpp) [40] which has been shown to be effective as an inducible vector against CT-26 tumors and metastases [23]. The different nutritional environment in a tumor may compensate for the metabolic defects in these bacteria, thereby allowing effective growth in a tumor but not in normal tissues [20, 39].

However, attenuation to reduce virulence in normal tissues might compromise the function of the bacteria in tumors. A large-scale study used a transposon library and a custom microarray to identify a group of Salmonella mutants that had reduced fitness or attenuation in normal tissues [41]. Their aim was to identify attenuated strains that retain their fitness inside tumors. Two classes of attenuated strains, those with minor or with moderate reductions in tumor fitness, were identified. STM3120, a severely attenuated SPI-3 mutant, had a minor reduction in tumor fitness and was effective in PC-3 tumors and somewhat effective in oral administration [41]. An araA mutant, similar to SL2707, had moderately reduced tumor fitness. However, this study examined bacterial fitness in tumors, not tumor killing ability.

In one embodiment, described herein is a modified bacteria comprising a strictly hypoxia regulated essential gene expressing cassette. By using recombinant technology, this cassette was introduced into the genome of facultative anaerobic gram-negative bacteria, including, but not limited to Salmonella typhimurium. A conditional "obligate" anaerobe strain YB1 is then produced. This strain YB1 was further applied to inhibit and reduce the growth of a solid tumor cancer when administered in vivo.

4.1 Method of Making a Hypoxia Targeted Salmonella Strain (YB1)

Replacement of the essential gene asd from parental Salmonella typhimurium strain SL2707 with a construct where this gene is under the control of hypoxia targeted promoters was achieved by recombinant technology (FIG. 3). In the resulting YB1 strain, the FNR related anaerobic capable promoter Pp(3)T controls transcription while an aerobic promoter, P sodA, facilitates transcription of antisense asd that blocks any leakage of Asd expression under aerobic conditions (FIG. 1A). If asd is not transcribed and DAP is not supplied in the environment, lysis of the YB1 bacteria occurs during bacterial growth.

Several other strain variants were constructed (YB-asd—SL2707 with no asd gene; YB1-pw—as YB1 but with no antisense promoter for asd; YB1-ew—as YB1 but with the Pp(3)T promoter replaced with a weaker anaerobic promoter (FIG. 1B, C). Regulation of Asd expression under high and low oxygen levels was tested. Changes in Asd protein levels were demonstrated by immunoblotting of myc tagged asd. The result (FIG. 6) showed that Asd expression in the YB1 (YB1-myc) strain was controlled by oxygen as expected: very strong Asd expression was detected under anaerobic condition whilst no such expression was observed under aerobic condition (YB1+O2 and YB1—O2). However, no Asd expression were observed under either aerobic or anaerobic conditions (EW+O2 and EW—O2) in strain YB1-ew (YB1-myc-ew) with the weak Pp(3)T promoter. In YB1-pw (YB1-myc-pw) strain without antisense promoter, leaky Asd expression was observed under aerobic conditions (PW+O2 and PW—O2).

All of the mutants were tested for growth in LB broth (FIG. 5A-D). Of the engineered strains in the absence of DAP, only YB1 showed the combination of growth under anaerobic culture conditions and repression in the aerobic environment. SL2707 and YB-pw showed growth in all conditions. YB-asp and YB-ew showed growth only with addition of DAP.

Serial reductions in the oxygen level and bacterial concentration were used to establish the range of conditions under which YB1 and the other strains could survive in the presence or absence of DAP. On LB agar plates without DAP, YB1 grew only when oxygen levels decreased to below 0.5%. Strains YB-asp and YB-ew did not grow in the absence of DAP, while SL2707 and YB-pw grew in all conditions (FIG. 7).

4.2 Ability of YB1 to Invade Cancer Cells

Breast cancer cell line MDA-MB-231 samples were incubated with YB1 or SL2707 under oxygen concentrations below 0.5% or aerobic conditions. After removal of extracellular bacteria and further culturing, confocal microscopy showed that both SL2707 and YB1 had invaded the breast cancer cells under anaerobic conditions (FIG. 8A, YB1—O2, SL2707—O2). In comparison, under aerobic conditions (FIG. 8A, YB1+O2, SL2707+O2), YB1 could not survive and only SL2707 was observed in breast cancer cells. In anaerobic conditions, by using an annexin V/PI assay, MDA-MB-231 samples treated with each of the bacteria showed an increase in the number of dying or apoptotic cells relative to a blank control (FIG. 8D), with YB1 being somewhat more effective in causing cell death or apoptosis (P<0.05) (FIG. 8C).

4.3 Accumulation of SL2707, YB1, and VNP20009 in Tumor and Normal Tissues In Vivo

Three groups of four-week-old nude mice were inoculated with breast cancer cells and, when tumor volumes reached 500-550 mm3, a single dose of SL2707 or YB1 or VNP20009 was injected via the tail vein. At varying time points, mice were euthanized and most organs and tumor were collected, homogenized and cultured on LB agar plates with antibiotics and DAP. CFU/gram was used as a relative measure of the degree of colonization of the tissues with bacteria.

For SL2707 inoculated mice, 1E+02 to 1E+04 CFU/gram of bacteria were found in all tissues at 6 hours (FIG. 9A), except for the level in blood which was much higher (1E+03 CFU/gram). Bacterial levels increased in all tissues subsequently with an uncontrolled infection by day 3 (FIG. 9A). The tumor to liver ratio of SL2707 was 2.78:1 at day 3. Mice started to die on day 7. On day 11, SL2707 levels in liver reached 3.8E+09 CFU/gram (FIG. 9A) and after that all mice died.
For YB1 injected mice, levels of bacteria were approximately the same as for the SL.7207 injected mice in all tissues 6 hours after inoculation (Fig. 9B), and bacteria were eliminated in the blood of 70% of the mice. After 1 day YB1 was eliminated from the blood and subsequently the levels in all normal tissues rapidly declined. In tumor, YB1 levels increased to a plateau of ~1E+08 CFU/gram by day 3 (Fig. 9B). The tumor to liver ratio of YB1 CFU/gram was ~7,000:1 on day 3 and 20,000:1 on day 7 (Fig. 9B). By day 26, YB1 was totally eliminated from heart, kidney, lung, lymph node, and spleen. YB1 was also eliminated from liver in five of the six mice tested, remaining in one mouse with a CFU/gram of 1.3E+03. YB1 showed significant preference in tumor than other organs (P<0.05 on day 5 and day 11, P<0.01 on day 7 and day 26). No YB1 was detected inside bone marrow within the whole process of the experiments.

The accumulation of VNP20009 in different organs was also evaluated by CFU test. Like YB1, VNP20009 also showed tumor preference (P<0.05) as previous reported (21, 47). The distribution in tumor reached to a plateau of ~3E+08 CFU/gram by day 5 (Fig. 9C). The best tumor to liver ratio was ~3,900:1 on day 5 (Fig. 9C). Compared with the SL.7207 strain, VNP20009 demonstrated quick clearance in normal organs, but at a slower elimination speed than YB1 in liver (P<0.05), kidney (P<0.05), spleen (P<0.05), lung, lymph node, and heart (Fig. 9).

Immuno-staining of sections of tumor and liver confirmed the distribution of Salmonella in these tissues. Both YB1 and SL.7207 targeted the tumor, with large amounts of bacteria being present from day 3 onwards (Fig. 10A). In liver, YB1 decreased and was almost undetected by day 7 with little effect on liver structure (Fig. 10B). For SL.7207 treated mice, continuing bacterial accumulation and liver damage were obvious (Fig. 10B).

For YB1 injected mice treated with YB1 (with or without a tumor) and YB1-asd treated tumor free mice survived more than 25 days as did mice (with or without a tumor) treated with PBS (Fig. 13B). SL.7207 treated mice started to die on days 5 and 7 with all mice dying by days 8 and 11 (without or with a tumor, respectively). SL.7207 treated mice with a tumor had a slightly better survival rate (Fig. 13B).

While the reduction in tumor growth in YB1 treated mice was marked compared with PBS treated mice, the tumor was still growing. Treatment of tumor bearing mice with the therapeutic agent 5-FU showed only a small reduction in tumor growth relative to PBS treatment (P<0.05). However, when 5-FU was given to YB1 infected tumor bearing mice, a much greater reduction in tumor size was observed than with the individual treatments (YB1+5-FU group vs. PBS group or 5-FU group showed P<0.05 on day 4 and P<0.01 from day 6 to day 15; YB1+5-FU group vs. YB1 group showed P<0.05 on day 6, 8, P<0.01 on day 10, 12, and P<0.01 on day 15) (Fig. 13C).

4.6 Comparison of Strain YB1 and VNP20009 in Tumor Regression and Targeting

To further evaluate the anti-tumor effect of YB1 strain, we compared it with the well-known tumor targeting strain VNP20009. A single dose of VNP20009 or YB1 was also injected via the tail vein to breast tumor bearing mice (tumor volume at bacterial inoculation ~360 mm³). The tumor size was measured every two days. Both YB1 (P<0.01) and VNP20009 (P<0.05) could delay tumor growth compared with PBS treatment group. However, YB1 showed stronger tumor inhibition than VNP20009 (P<0.05) (Fig. 13D).

4.7 YB1 Treatment of Liver Cancer in Nude Mice Model

In MHCC97-L liver cancer model, a single dose of YB1 treatment showed significant repression of liver cancer growth and metastasis (Fig. 14). The tumor growth was compared between the groups with YB1 treatment and PBS treatment, which was monitored by Xenogen IVIS imaging system (Fig. 14A). Distant lung metastasis was confirmed after histology examination (Fig. 14C). The imaging results showed the tumor was starting to shrink in size after 10 days’ YB1 treatment. After 3 weeks, the tumor size of all treatment mice showed dramatically reduction. Some mice even showed total elimination of tumors (Fig. 14).

5. EXAMPLES

5.1 Cloning and Assembling Strictly Hypoxia Regulated an Essential Gene Expressing Cassette

Bacteria and plasmids used or created here are given in Table 1 and primers used are in Table 2. The asd gene and the promoter of the pepT gene were cloned from the chromosome of SL.7207 by PCR with primer pairs asd-C-F and asd-C-R, pepT-F and pepT-R (preheating at 95°C for 5 mins, followed by 30 cycles of denaturing at 95°C for 30 seconds, annealing at 60°C for 30 seconds, elongation at 72°C for 1 min, with final extension at 72°C for 10 minutes, and then cooling to room temperature) whilst asd-myc was generated with the asd-C-F and asd-C-myc-R primer pair. PausB and PsoD (promoters of asnB and sodA) constructs were generated by an annealing process with oligonucleotide pairs asnB-3′ and asnB-5′, sodA-3′ and sodA-5′ (10 μM forward and reverse primers).
reverse primers were mixed and heated at 95°C for 5 mins, and placed at room temperature for 30 mins). The antibiotic marker was amplified by PCR with primers cm-F and cm-R from a plox-cm-lox template [51]. The plasmids for the aad expression vectors were built on the backbone of pbLuescript II SK (pBSK) which was digested by HindIII, XhoI, NotI and PsiI. After ligation by T4 ligase, plasmids pYB1 (pBSK-cm-PepT-asaPsdodA), pYB1-myc (pBSK-cm-PepT-asaPsdodA), pYB-pw (pBSK-cm-PepT-asaPsdodA), pYB-myc-pw (pBSK-cm-PepT-asaPsdodA), pYB-ew (pBSK-cm-PansB-asaPsdodA), and pYB-myc-ew (pBSK-cm-PansB-asaPsdodA) were generated.

### Table 1

<table>
<thead>
<tr>
<th>Strain</th>
<th>Relevant genotype or characteristics</th>
<th>Ref. or source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S. typhimurium</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL7207</td>
<td>hisG46 delG47 [anaA::Tn10 (Te²)]; wild type in this study</td>
<td>[1]</td>
</tr>
<tr>
<td>VN20009</td>
<td>YSS2; Apur, AmsB</td>
<td>ATCC</td>
</tr>
<tr>
<td>YB1</td>
<td>SL7207; Cm²; AmsB::PepT-asaPsdodA</td>
<td>This patent</td>
</tr>
<tr>
<td>YB1-myc</td>
<td>SL7207; Cm²; AmsB::PepT-asaPsdodA</td>
<td>This patent</td>
</tr>
<tr>
<td>YB-aad</td>
<td>SL7207; Cm²; AmsB</td>
<td>This patent</td>
</tr>
<tr>
<td>YB-pw</td>
<td>SL7207; Cm²; AmsB::PepT-asaPsdodA</td>
<td>This patent</td>
</tr>
<tr>
<td>YB-myc-pw</td>
<td>SL7207; Cm²; AmsB::PepT-asaPsdodA</td>
<td>This patent</td>
</tr>
<tr>
<td>YB-ew</td>
<td>SL7207; Cm²; AmsB::PansB-asaPsdodA</td>
<td>This patent</td>
</tr>
<tr>
<td>YB-myc-ew</td>
<td>SL7207; Cm²; AmsB::PansB-asaPsdodA</td>
<td>This patent</td>
</tr>
<tr>
<td><strong>Plasmid</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pbLuescript II SK</td>
<td>Ap²; cloning vector</td>
<td>Stratagene</td>
</tr>
<tr>
<td>plox-cm-lox</td>
<td>Ap²; Cm²; pBSK derivative containing lox-p-cm-lox fragment</td>
<td>[2, 3]</td>
</tr>
<tr>
<td>pSim6</td>
<td>Ap²; Lambda-ori recombinase plasmid</td>
<td>[4]</td>
</tr>
<tr>
<td>p70/Cm-Km</td>
<td>Km²; cm-recombinase expressing plasmid</td>
<td>[2]</td>
</tr>
<tr>
<td>pYB1</td>
<td>Ap²; Cm²; pBSK derivative with cm-PepT-asaPsdodA fusion</td>
<td>This patent</td>
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<tr>
<td>pYB1-myc</td>
<td>Ap²; Cm²; pBSK derivative with cm-PepT-asaPsdodA fusion</td>
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<tr>
<td>pYB-pw</td>
<td>Ap²; Cm²; pBSK derivative with cm-PepT-asaPsdodA fusion</td>
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<tr>
<td>pYB-ew</td>
<td>Ap²; Cm²; pBSK derivative with cm-PansB-asaPsdodA fusion</td>
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</tr>
<tr>
<td>pYB-myc-ew</td>
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### Table 2

<table>
<thead>
<tr>
<th>Primers</th>
<th>Sequence (5' - 3')</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>pepT-P</td>
<td>ATTTGCGCGCAGCTAAAGGCAAGAGGTGTTGTCGACC</td>
<td>pepT promoter</td>
</tr>
<tr>
<td>pepT-R</td>
<td>CCAGAAGCTTCTTCCGAGCAACATATATTAG</td>
<td></td>
</tr>
<tr>
<td>asd-C-F</td>
<td>CCCGAAGCTTCAAGAAGACACATGAAATGCAATGATATTT</td>
<td>and gene with or without myo-tag</td>
</tr>
<tr>
<td>asd-C-R</td>
<td>CGGTACGCACTGACGACTCTGCTTC</td>
<td></td>
</tr>
<tr>
<td>asd-myc-C-R</td>
<td>CGGTACGCACTGACGACTCTGCTTC</td>
<td></td>
</tr>
<tr>
<td>ansB-P</td>
<td>ATTTGCGCGCAGCTAAAGGCAAGAGGTGTTGTCGACC</td>
<td>ansB promoter</td>
</tr>
<tr>
<td>ansB-R</td>
<td>CCAGAAGCTTCTTCCGAGCAACATATATTAG</td>
<td></td>
</tr>
<tr>
<td>sodA-P</td>
<td>ATTTGCGCGCAGCTAAAGGCAAGAGGTGTTGTCGACC</td>
<td>sodA promoter</td>
</tr>
<tr>
<td>sodA-R</td>
<td>CCAGAAGCTTCTTCCGAGCAACATATATTAG</td>
<td></td>
</tr>
<tr>
<td>cm-F</td>
<td>ATTTGCGCGCAGCTAAAGGCAAGAGGTGTTGTCGACC</td>
<td>chloramphenicol</td>
</tr>
<tr>
<td>cm-R</td>
<td>ATTTGCGCGCAGCTAAAGGCAAGAGGTGTTGTCGACC</td>
<td>resistance gene</td>
</tr>
</tbody>
</table>
### TABLE 2—continued

<table>
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<tr>
<th>Primer</th>
<th>Sequence (5’-3’)</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>asd-F</td>
<td>GATAYCCTAGAGCTGGCCGACACCAGAAGCTGGCCGCGATAAC</td>
<td>knock-out asd gene from SL7207 chromosome</td>
</tr>
<tr>
<td>asd-R</td>
<td>ATGCAGGGCTTCATCCGCTTCAGGCACCAAGACACAC</td>
<td></td>
</tr>
<tr>
<td>YB1-F</td>
<td>GYXGCGCGCGCGATCAGGTCCCGCAGATCGGCGAG</td>
<td>knock-in oxygen response cassette to SL7207 chromosome</td>
</tr>
<tr>
<td>YB1-R</td>
<td>TGGATTAAGCTGCCGCGGAGCTGAGGGGAGGGG</td>
<td></td>
</tr>
<tr>
<td>YB1-test-F</td>
<td>GATCTGCTCTCCGTCTG</td>
<td>Verification of insertion</td>
</tr>
<tr>
<td>YB1-test-R</td>
<td>ACRITCCAGTTGCGACTT</td>
<td></td>
</tr>
</tbody>
</table>

5.2 Construction of Oxygen Sensitive *Salmonella* Mutant (YB1)

**[0068]** The λ-red recombination system (plasmid pSim6) [52] was used to replace the asd gene with the cm-PepT1-asd-sodA genetic circuit in SL7207. As a first step the target asd gene was generated with a plox-cm-loxP template in a PCR reaction, elecrotopherated into recombination-competent cells and selected on chloramphenicol Luria-Bertani (LB) plates. Antibiotic resistance genes were removed by site-specific Cre/loxP mediated recombination by transformation of plasmid p705cre-Km, generating the strain YB1-asd. Next, the cm-PepT1-asd-sodA genetic circuit was amplified from plasmid pYB1 and, after recombinant, the correct colony was selected and confirmed by PCR giving strain YB1. Strains YB1-lis, YB1-pw, and YB1-ew were constructed similarly with the plasmids pYB1-myc, pYB1-pw, pYB1-pw-myc, pYB1-ew, and pYB1-ew as templates, respectively (Fig. 3).

5.3 YB1 in Different Environments

**[0069]** By controlling essential gene asd with inducible promoters, facultative anaerobic gram-negative bacteria were transferred into an "obligate" anaerobe without otherwise interfering with the function of the bacterium. This novel kind "obligate" anaerobe is reversible. It has two phases: under anaerobic condition, it could grow and live as normal facultative anaerobic gram-negative bacteria; under aerobic condition, it has two choices. With additional chemical dinitrophenol acid (DAP), YB1 could act full functional as facultative anaerobic gram-negative bacteria, but without DAP, it could lyse and die in short period time. Therefore, oxygen and DAP are two important factors to control "obligate" anaerobic ability of YB1 (Fig. 4).

**[0070]** To test the growth of *Salmonella* strains and mutants under aerobic and anaerobic conditions, bacterial strains were grown in LB medium at 37°C, with shaking at 220 rpm over night. Aerobic conditions were achieved by shaking in broth, and anaerobic cultures were either grown in anaerobic tubes or an anaerobic jar (Mitsubishi Gas Chemical Company). Overnight cultures of *Salmonella* strains SL7207, YB1-asd, YB1, YB1-pw, and YB1-ew were counted and diluted into samples at 5E+04 colony forming units (CFU)/ml, with each strain divided into two groups (with or without DAP) in LB broth, OD600 was measured every 30 minutes for aerobic cultures, and each hour for anaerobic cultures from 0 hours to 24 hours. For LB agar plate assays, an anaerobic jar was applied to generate different oxygen concentrations by combinations of AnaeroPacks and monitored by an oxygen meter. Ten serial dilutions of individual drops from a high concentration of 5E+06 CFU/ml to 5E+01 CFU/ml, where each drop contained 10 d of bacterial culture, were added to plates that were cultured in anaerobic jar at 37°C, for 2 days. The results were showed in FIGS. 5 & 7.

5.4 Bacteria Strains Invasion of Breast Cancer Cells in vitro

**[0071]** *Salmonella* and MDA-MB-231 cells were prepared and co-cultured at a ratio of 1000–500:1 for 2 hours under anaerobic (O2<0.5%) or aerobic conditions. The cells were then washed with PBS and cultured in gentamycin supplemented medium to remove extracellular bacteria. 24 hours later, cells were fixed in paraformaldehyde (4%) and stained with an anti-Salmonella antibody (1:500, Abeam) overnight at 4°C. A Cy3 conjugated secondary antibody was added and incubated for 1 hour at room temperature. Then FITC conjugated Phallolidin (1:1000) was applied to indicate cell boundaries. Images were observed under a confocal microscope. Cancer cell apoptosis and death induced by bacteria under anaerobic conditions were detected by an annexin V-PI kit (Biovision) according to manufacturer’s instructions. As shown by flow cytometry, annexin V+/PI- cells are apoptotic and annexin V+/PI+ cells are dead. The results were showed in FIG. 8.

5.5 Bacteria Strains in the Treatment of Breast Cancer Nude Mice Model

**[0072]** 5E+05 MDA-MB-231 cells were inoculated at the fat pad of four-week-old nude mice. The tumor volumes were calculated by the following formula: $4/3\pi(xw^2)/8$, where $h$ is the height and $w$ is the width. When the tumors grew to about 500–550 mm³ (15–19 days), mice were divided into groups for experiments. If tumors reached 4000 mm³, mice were euthanized.

**[0073]** To measure the effect of bacterial inoculation on mouse survival and tumor growth, two groups of 10 mice were treated with either YB1 (5E+07 CFU), SL7207 (5E+07 CFU), and 6 mice for PBS group with volume of 100 µl injected through the tail vein (i.v.). Tumor size (starting volume is about 500–550 mm³) was measured by caliper every 2 to 3 days (FIG. 13 A). Mouse survival rate was recorded (FIG. 13 B). For VNP20009 and YB1 comparison test, additional 6 mice for each group were administrated with same dose (5E+07 CFU), but with smaller tumor starting size (about 360 mm³) (FIG. 13 D).
To measure the bacterial distribution after inoculation, mice were treated with the same method as above and sacrificed at the indicated time points (a total of 6 mice of YB1 group and SL7207 group for each time point; 5 mice of VNP20009 group for each time point) and tissues were weighed, homogenized, serially diluted in PBS and plated with the required antibiotics and DAP. CFU were counted after two days growth. The experiments of YB1 and SL7207 treatment were repeated three times with two mice per time point per experiment; the experiments of VNP20009 treatment were repeated two times with 2-3 mice per time point per experiment (FIG. 9).

A possible synergistic effect of YB1 and 5-FU was tested in 48 tumor-bearing mice that were divided into four groups with 12 mice each and treated with PBS, PBS with 5-FU (60 mg/Kg), a single dose of YB1 (5E+07 CFU) or a single dose of YB1 (5E+07 CFU) plus 5-FU. For the 5-FU treatment groups, 5-FU was intra-peritoneal (i.p.) injected every four days starting from day 3 after bacterial injection (FIG. 13C).

Male nude mice 4-6 weeks old were used. MiHCC97L cells of 6E+05 were injected into the right flank subcutaneously of each mouse. Once the tumor reached to 0.8-1 cm in diameter, they were surgically removed and cut into cubes with 1-2 mm³ in volume. Then the tumor seeds were implanted into the left liver lobes of another healthy nude mice group [54] for another 2 weeks. The dose of 5E+07 CFU of YB1 were applied to treat mice. The tumor growth was monitored by Xenogen IVIS 100 at different time points after YB1 treatment on day 0, day 10, week 2, and week 3. Each mouse was i.p. with 100 μg D-luciferin before imaging. The results were shown in FIG. 14.

The dorsal skinfold window chamber is a sophisticated animal model, which could observe dynamic interaction of certain region with surrounding host tissue in mice. This chronic model offers a repeatable analysis of tumor progression, treatment, and angiogenesis during 2-3 weeks after tumor implantation [55, 56].

5.7.1 Construct ‘Window Chamber’ Animal Model

In the surgery, first, anesthetized mouse was placed it on a thermosstat blanket to maintain the body temperature. Second, the mouse was sterilized most skin of by 70% ethanol. Third, the dorsal skin was gently pulled loose, and attached with two pieces of window chamber clamps. Fourth, both sides of the skin were punched with three holes at the screw positions by 18 g needle. Fifth, the screws were inserted and fixed on the front window chamber though three holes (FIG. 15A). Sixth, the forward layer skin was hold by mosquito forceps and cut, and left the opposing layer intact. Seventh, about 20 μl tumor cells suspension were injected by 29 g syringe between the layer of fascial plane and dermis. Eighth, a glass coverslip was placed on the window and secured with retaining ring (FIGS. 15B, 15C). To avoid infection, each mouse was giving 500 mg streptomycin everyday by i.p. injection. This procedure was adapted from Palmer’s protocol [56].
YB1 within liver or spleen after three weeks' treatment. The result indicated YB1 was safe to administrate with 5E+08 CFU or lower by i.v. injection in Buffalo rat, which was 10 times higher than in mouse model.

6. HUMAN TREATMENT

6.1 Formulations

[0085] The modified bacteria provided herein can be administered to a patient in the conventional form of preparations, such as injections and suspensions. Suitable formulations can be prepared by methods commonly employed using conventional, organic or inorganic additives, such as an excipient selected from fillers or diluents, binders, disintegrants, lubricants, flavoring agents, preservatives, stabilizers, suspending agents, dispersing agents, surfactants, antioxidants or solubilizers.

[0086] Excipients that may be selected are known to those skilled in the art and include, but are not limited to fillers or diluents (e.g., sucrose, starch, mannitol, sorbitol, lactose, glucose, cellulose, tate, calcium phosphate or calcium carbonate and the like), a binder (e.g., cellulose, carboxymethylcellulose, methylcellulose, hydroxyethylcellulose, hydroxypropylcellulose, polypropylene glycol, polyvinylpyrrolidone, gelatin, gum arabic, polyethylene glycol or starch and the like), a disintegrant (e.g., sodium starch glycolate, croscarmellose sodium and the like), a lubricant (e.g., magnesium stearate, light anhydrous silicie acid, tate or sodium lauryl sulfate and the like), a flavoring agent (e.g., citric acid, menthol and the like), a preservative (e.g., sodium benzoate, sodium bisulfite, propylparaben or propylparaben and the like), a stabilizer (e.g., citric acid, sodium citrate or acetic acid and the like), a suspending agent (e.g., methylcellulose, polyvinyl pyrrolidone or aluminum stearate and the like), a dispersing agent (e.g., hydroxypropylcellulose and the like), surfactants (e.g., sodium lauryl sulfate, poloxamer, polyaloxanes and the like), antioxidants (e.g., ethylene diamine tetraacetic acid (EDTA), butylated hydroxy tolue (BHT) and the like) and solubilizers (e.g., polyethylene glycol, SOLUTOL® S61, GELUCIRE® and the like). The effective amount of the modified bacteria provided herein in the pharmaceutical composition may be at a level that will exercise the desired effect.

[0087] In another embodiment, provided herein are compositions comprising an effective amount of modified bacteria provided herein and a pharmaceutically acceptable carrier or vehicle, wherein a pharmaceutically acceptable carrier or vehicle can comprise an excipient, a diluent, or a mixture thereof. In one embodiment, the composition is a pharmaceutical composition.

[0088] Compositions can be formulated to contain a daily dose, or a convenient fraction of a daily dose, in a dosage unit. In general, the composition is prepared according to known methods in pharmaceutical chemical. Capsules can be prepared by mixing the modified bacteria provided herein with a suitable carrier or diluent and filling the proper amount of the mixture in capsules;

6.2 Method of Use

[0089] Solid tumor cancers that can be treated by the methods provided herein include, but are not limited to, sarcomas, carcinomas, and lymphomas. In specific embodiments, cancers that can be treated in accordance with the methods described include, but are not limited to, cancer of the breast, liver, neuroblastoma, head, neck, eye, mouth, throat, esophagus, esophagus, chest, bone, lung, kidney, colon, rectum or other gastrointestinal tract organs, stomach, spleen, skeletal muscle, subcutanous tissue, prostate, breast, ovaries, testicles or other reproductive organs, skin, thyroid, blood, lymph nodes, kidney, liver, pancreas, and brain or central nervous system.

[0090] In particular embodiments, the methods for treating cancer provided herein inhibit, reduce, diminish, arrest, or stabilize a tumor associated with the cancer. In other embodiments, the methods for treating cancer provided herein inhibit, reduce, diminish, arrest, or stabilize the blood flow, metabolism, or edema in a tumor associated with the cancer or one or more symptoms thereof. In specific embodiments, the methods for treating cancer provided herein cause the regression of a tumor, tumor blood flow, tumor metabolism, or peritumor edema, and/or one or more symptoms associated with the cancer. In another embodiments, the methods for treating cancer provided herein maintain the size of the tumor so that it does not increase, or so that it increases by less than the increase of a tumor after administration of a standard therapy as measured by conventional methods available to one of skill in the art, such as digital rectal exam, ultrasound (e.g., transrectal ultrasound), CT Scan, MRI, dynamic contrast-enhanced MRI, or PET Scan. In specific embodiments, the methods for treating cancer provided herein decrease tumor size. In certain embodiments, the methods for treating cancer provided herein reduce the formation of a tumor. In certain embodiments, the methods for treating cancer provided herein eradicate, remove, or control primary, regional and/or metastatic tumors associated with the cancer. In some embodiments, the methods for treating cancer provided herein decrease the number or size of metastases associated with the cancer.

[0091] In certain embodiments, the methods for treating cancer provided herein reduce the tumor size (e.g., volume or diameter) in a subject by at least about 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 99%, or 100%, relative to tumor size (e.g., volume or diameter) prior to administration of modified bacteria as assessed by methods well known in the art, e.g., CT Scan, MRI, DCE-MRI, or PET Scan. In particular embodiments, the methods for treating cancer provided herein reduce the tumor volume or tumor size (e.g., diameter) in a subject by an amount in the range of about 5% to 20%, 10% to 20%, 10% to 30%, 15% to 40%, 15% to 50%, 20% to 30%, 20% to 40%, 20% to 50%, 30% to 60%, 30% to 70%, 30% to 80%, 30% to 90%, 30% to 95%, 30% to 99%, 30% to 100%, or any range in between, relative to tumor size (e.g., diameter) in a subject prior to administration of modified bacteria as assessed by methods well known in the art, e.g., CT Scan, MRI, DCE-MRI, or PET Scan.

[0092] In certain embodiments, the methods for treating cancer provided herein reduce the tumor perfusion in a subject by at least about 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 80%, 85%, 90%, 95%, 99%, or 100%, relative to tumor perfusion prior to administration of modified bacteria as assessed by methods well known in the art, e.g., MRI, DCE-MRI, or PET Scan. In particular embodiments, the methods for treating cancer provided herein reduce the tumor perfusion in a subject by an amount in the range of about 5% to 20%, 10% to 20%, 10% to 30%, 15% to 40%, 15% to 50%, 20% to 30%, 20% to 40%,
20% to 50%, 30% to 60%, 30% to 70%, 30% to 80%, 30% to 90%, 30% to 95%, 30% to 99%, 30% to 100%, or any range in between, relative to tumor perfusion prior to administration of modified bacteria, as assessed by methods well known in the art, e.g., MRI, DCE-MRI, or PET Scan.

[0093] In particular aspects, the methods for treating cancer provided herein inhibit or decrease tumor metabolism in a subject as assessed by methods well known in the art, e.g., PET scanning. In specific embodiments, the methods for treating cancer provided herein inhibit or decrease tumor metabolism in a subject by at least about 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 80%, 85%, 90%, 95%, or 100%, relative to tumor metabolism prior to administration of modified bacteria, as assessed by methods well known in the art, e.g., PET scanning. In particular embodiments, the methods for treating cancer provided herein inhibit or decrease tumor metabolism in a subject in the range of about 5% to 20%, 10% to 20%, 10% to 30%, 15% to 40%, 15% to 50%, 20% to 30%, 20% to 40%, 20% to 50%, 30% to 60%, 30% to 70%, 30% to 80%, 30% to 90%, 30% to 95%, 30% to 99%, 30% to 100%, or any range in between, relative to tumor metabolism prior to administration of modified bacteria, as assessed by methods well known in the art, e.g., PET scan.

6.3 Patient Population

[0094] In some embodiments, a subject treated for cancer in accordance with the methods provided herein is a human who has or is diagnosed with cancer. In other embodiments, a subject treated for cancer in accordance with the methods provided herein is a human predisposed or susceptible to cancer. In some embodiments, a subject treated for cancer in accordance with the methods provided herein is a human at risk of developing cancer.

[0095] In one embodiment, a subject treated for cancer in accordance with the methods provided herein is a human infant. In another embodiment, a subject treated for cancer in accordance with the methods provided herein is a human toddler. In another embodiment, a subject treated for cancer in accordance with the methods provided herein is a human child. In another embodiment, a subject treated for cancer in accordance with the methods provided herein is a human adult. In another embodiment, a subject treated for cancer in accordance with the methods provided herein is a middle-aged human. In another embodiment, a subject treated for cancer in accordance with the methods provided herein is an elderly human.

[0096] In certain embodiments, a subject treated for cancer in accordance with the methods provided herein has a cancer that metastasized to other areas of the body, such as the bones, lung and liver. In certain embodiments, a subject treated for cancer in accordance with the methods provided herein in remission from the cancer. In some embodiments, a subject treated for cancer in accordance with the methods provided herein has a recurrence of the cancer. In certain embodiments, a subject treated in accordance with the methods provided herein is experiencing recurrence of one or more tumors associated with cancer.

[0097] In certain embodiments, a subject treated for cancer in accordance with the methods provided herein is a human that is about 1 to about 5 years old, about 5 to 10 years old, about 10 to about 18 years old, about 18 to about 30 years old, about 25 to about 35 years old, about 35 to about 45 years old, about 40 to about 55 years old, about 50 to about 65 years old, about 60 to about 75 years old, about 70 to about 85 years old, about 80 to about 90 years old, about 90 to about 95 years old or about 95 to about 100 years old, or any age in between. In a specific embodiment, a subject treated for cancer in accordance with the methods provided herein is a human that is 18 years old or older. In a particular embodiment, a subject treated for cancer in accordance with the methods provided herein is a human child that is between the age of 1 year old to 18 years old. In a certain embodiment, a subject treated for cancer in accordance with the methods provided herein is a human that is between the age of 12 years old and 18 years old. In a certain embodiment, the subject is a male human. In another embodiment, the subject is a female human. In one embodiment, the subject is a female human that is not pregnant or is not breastfeeding. In one embodiment, the subject is a female that is pregnant or will/might become pregnant, or is breastfeeding.

[0098] In some embodiments, a subject treated for cancer in accordance with the methods provided herein is administrated modified bacteria or a pharmaceutical composition thereof, or a combination therapy before any adverse effects or intolerance to therapies other than the modified bacteria develops. In some embodiments, a subject treated for cancer in accordance with the methods provided herein is a refractory patient. In a certain embodiment, a refractory patient is a patient refractory to a standard therapy (e.g., surgery, radiation, anti-androgen therapy and/or drug therapy such as chemotherapy). In certain embodiments, a patient with cancer is refractory to a therapy when the cancer has not significantly been eradicated and/or the one or more symptoms have not been significantly alleviated. The determination of whether a patient is refractory can be made either in vivo or in vitro by any method known in the art for assessing the effectiveness of a treatment of cancer, using art-accepted meanings of "refractory" in such a context. In various embodiments, a patient with cancer is refractory when one or more tumors associated with cancer, have not decreased or have increased. In various embodiments, a patient with cancer is refractory when one or more tumors metastasize and/or spread to another organ.

[0099] In some embodiments, a subject treated for cancer in accordance with the methods provided herein is a human that has proven refractory to therapies other than treatment with modified bacteria, but is no longer on these therapies. In certain embodiments, a subject treated for cancer in accordance with the methods provided herein is a human already receiving one or more conventional anti-cancer therapies, such as surgery, drug therapy such as chemotherapy, anti-androgen therapy or radiation. Among these patients are refractory patients, patients who are too young for conventional therapies, and patients with recurring tumors despite treatment with existing therapies.

6.4 Dosage

[0100] In one aspect, a method for treating cancer presented herein involves the administration of a unit dosage of modified bacteria thereof. The dosage may be administered as often as determined effective (e.g., once, twice or three times per day, every other day, once or twice per week, biweekly or monthly). In certain embodiments, a method for treating cancer presented herein involves the administration to a subject in need thereof of a unit dose of modified bacteria that can be determined by one skilled in the art.

[0101] In some embodiments, a unit dose of modified bacteria or a pharmaceutical composition thereof is administered...
to a subject once per day, twice per day, three times per day; once, twice or three times every other day (i.e., on alternate days); once, twice or three times every two days; once, twice or three times every three days; once, twice or three times every four days; once, twice or three times every five days; once, twice, or three times once a week, biweekly or monthly, and the dosage may be administered orally.

6.5 Combination Therapy

[0102] Presented herein are combination therapies for the treatment of cancer which involve the administration of modified bacteria in combination with one or more additional therapies to a subject in need thereof. In a specific embodiment, presented herein are combination therapies for the treatment of cancer which involve the administration of an effective amount of modified bacteria in combination with an effective amount of another therapy to a subject in need thereof.

[0103] As used herein, the term “in combination,” refers, in the context of the administration of modified bacteria, to the administration of modified bacteria prior to, concurrently with, or subsequent to the administration of one or more additional therapies (e.g., agents, surgery, or radiation) for use in treating cancer. The use of the term “in combination” does not restrict the order in which modified bacteria and one or more additional therapies are administered to a subject. In specific embodiments, the interval of time between the administration of modified bacteria and the administration of one or more additional therapies may be about 1.5 minutes, 1-30 minutes, 30 minutes to 60 minutes, 1 hour, 1-2 hours, 2-6 hours, 2-12 hours, 12-24 hours, 1-2 days, 2 days, 3 days, 4 days, 5 days, 6 days, 7 days, 1 week, 2 weeks, 3 weeks, 4 weeks, 5 weeks, 6 weeks, 7 weeks, 8 weeks, 9 weeks, 10 weeks, 15 weeks, 20 weeks, 25 weeks, 52 weeks, 11-15 weeks, 15-20 weeks, 20-30 weeks, 30-40 weeks, 40-50 weeks, 1 month, 2 months, 3 months, 4 months, 5 months, 6 months, 7 months, 8 months, 9 months, 10 months, 11 months, 12 months, 1 year, 2 years, or any period of time in between. In certain embodiments, modified bacteria and one or more additional therapies are administered less than 1 day, 1 week, 2 weeks, 3 weeks, 4 weeks, one month, 2 months, 3 months, 6 months, 1 year, 2 years, or 5 years apart.

[0104] In some embodiments, the combination therapies provided herein involve administering modified bacteria daily, and administering one or more additional therapies once a week, once every 2 weeks, once every 3 weeks, once every 4 weeks, once every month, once every 2 months (e.g., approximately 8 weeks), once every 3 months (e.g., approximately 12 weeks), or once every 4 months (e.g., approximately 16 weeks). In certain embodiments, modified bacteria and one or more additional therapies are cyclically administered to a subject. Cycling therapy involves the administration of modified bacteria for a period of time, followed by the administration of one or more additional therapies for a period of time, and repeating this sequential administration. In certain embodiments, cycling therapy may also include a period of rest where modified bacteria or the additional therapy is not administered for a period of time (e.g., 2 days, 3 days, 4 days, 5 days, 6 days, 7 days, 1 week, 2 weeks, 3 weeks, 4 weeks, 5 weeks, 10 weeks, 20 weeks, 1 month, 2 months, 3 months, 4 months, 5 months, 6 months, 7 months, 8 months, 9 months, 10 months, 11 months, 12 months, 2 years, or 3 years). In an embodiment, the number of cycles administered is from 1 to 12 cycles, from 2 to 10 cycles, or from 2 to 8 cycles.

[0105] In some embodiments, the methods for treating cancer provided herein comprise administering modified bacteria as a single agent for a period of time prior to administering the modified bacteria in combination with an additional therapy. In certain embodiments, the methods for treating cancer provided herein comprise administering an additional therapy alone for a period of time prior to administering modified bacteria in combination with the additional therapy.

[0106] In some embodiments, the administration of modified bacteria and one or more additional therapies in accordance with the methods presented herein have an additive effect relative to the administration of modified bacteria or said one or more additional therapies alone. In some embodiments, the administration of modified bacteria and one or more additional therapies in accordance with the methods presented herein have a synergistic effect relative to the administration of the Compound or said one or more additional therapies alone.

[0107] As used herein, the term “synergistic,” refers to the effect of the administration of modified bacteria in combination with one or more additional therapies (e.g., agents), which combination is more effective than the additive effects of any two or more single therapies (e.g., agents). In a specific embodiment, a synergistic effect of a combination therapy permits the use of lower dosages (e.g., sub-optimal doses) of modified bacteria or an additional therapy and/or less frequent administration of modified bacteria or an additional therapy to a subject. In certain embodiments, the ability to utilize lower dosages of modified bacteria or of an additional therapy and/or to administer modified bacteria or said additional therapy less frequently reduces the toxicity associated with the administration of modified bacteria or of said additional therapy, respectively, to a subject without reducing the efficacy of modified bacteria or of said additional therapy, respectively, in the treatment of cancer. In some embodiments, a synergistic effect results in improved efficacy of modified bacteria and each of said additional therapies in treating cancer. In some embodiments, a synergistic effect of a combination of modified bacteria and one or more additional therapies avoids or reduces adverse or unwanted side effects associated with the use of any single therapy.

[0108] The combination of modified bacteria and one or more additional therapies can be administered to a subject in the same pharmaceutical composition. Alternatively, modified bacteria and one or more additional therapies can be administered concurrently to a subject in separate pharmaceutical compositions. Modified bacteria and one or more additional therapies can be administered sequentially to a subject in separate pharmaceutical compositions. Modified bacteria and one or more additional therapies may also be administered to a subject by the same or different routes of administration.

[0109] The combination therapies provided herein involve administering to a subject in need thereof modified bacteria in combination with conventional, or known, therapies for treating cancer. Other therapies for cancer or a condition associated therewith are aimed at controlling or relieving one or more symptoms. Accordingly, in some embodiments, the combination therapies provided herein involve administering to a subject in need thereof a pain reliever, or other therapeutically active agent.
pies aimed at alleviating or controlling one or more symptoms associated with or a condition associated therewith.

[0110] Specific examples of anti-cancer agents that may be used in combination with modified bacteria include: a hormonal agent (e.g., aromatase inhibitor, selective estrogen receptor modulator (SERM), and estrogen receptor antagonist), chemotherapeutic agent (e.g., microtubule disassembly blocker, antimetabolite, topoisomerase inhibitor, and DNA crosslinker or damaging agent), anti-angiogenic agent (e.g., VEGF antagonist, receptor antagonist, integrin antagonist, vascular targeting agent (VTA)/vascular disrupting agent (VDA)), radiation therapy, and conventional surgery.

[0111] Non-limiting examples of hormonal agents that may be used in combination with modified bacteria include: aromatase inhibitors, SERMs, and estrogen receptor antagonists. Hormonal agents that are aromatase inhibitors may be steroidal or nonsteroidal. Non-limiting examples of nonsteroidal hormonal agents include letrozole, anastrozole, aminoglutethimide, fadrozole, and vorozole. Non-limiting examples of steroidal hormonal agents include aminoglutethimide (exemestane), formestane, and testolactone. Non-limiting examples of steroidal hormonal agents that are SERMs include tamoxifen (branded/marketed as Nolvadex®), afaxifene, arzoxifene, bazodroxifene, clomifene, tamoxifene, laosfoxifene, ormeloxifene, raloxifene, and toremifene. Non-limiting examples of hormonal agents that are estrogen receptor antagonists include fulvestrant. Other hormonal agents include but are not limited to aminoglutethimide and loniparib.

[0112] Non-limiting examples of chemotherapeutic agents that may be used in combination with modified bacteria include: microtubule disassembly blocker, antimetabolite, topoisomerase inhibitor, and DNA crosslinker or damaging agent. Chemotherapeutic agents that are microtubule disassembly blockers include, but are not limited to: taxanes (e.g., paclitaxel (branded/marketed as TAXOL®), docetaxel, abraxane, loratexol, ortaxol, and tesstaxel); epothilones (e.g., ixabepilone); and vinca alkaloids (e.g., vincristine, vindesine, and vincristine (branded/marketed as ONCOVIN®)).

[0113] Chemotherapeutic agents that are antimetabolites include, but are not limited to, folate antimetabolites (e.g., methotrexate, aminopterin, pemtrexed, raltrexed); purine antimetabolites (e.g., cladribine, chlorambucil, fludarabine, mercaptopurine, pentostatin, thioguanine; pyrimidine antimetabolites (e.g., 5-fluorouracil, capcitabine, gemcitabine (GEMZAR®), cytarabine, decitubine, fluoruridine, tegafur); and deoxyribonucleoside antimetabolites (e.g., hydroxyurea).

[0114] Chemotherapeutic agents that are topoisomerase inhibitors include, but are not limited to, class I (camptotheca) topoisomerase inhibitors (e.g., topotecan (branded/marketed as HYCAMTIN®) irinotecan, rubitecan, and belotecan); class II (podophyllum) topoisomerase inhibitors (e.g., etoposide or VP-16, and teniposide); anthracyclines (e.g., doxorubicin, epirubicin, Doxi, aclacinomycin, amrubicin, daunorubicin, idarubicin, pirarubicin, valrubicin, and zorubicin); and anthracteocedines (e.g., mitoxantrone, and pixantrone).

[0115] Chemotherapeutic agents that are DNA crosslinkers (or DNA damaging agents) include, but are not limited to, alkylating agents (e.g., cyclophosphamide, mechlorethamine, ifosfamide (branded/marketed as IFEX®, trofosfamide, chlorambucil, melphalan, prednimustine, bendamustine, uramustine, estramustine, carmustine (branded/marketed as BiCNU), lomustine, semustine, fotemustine, nimustine, ramustine, streptozocin, busulfan, mannosulfan, trofosfamide, carboquone, NNK-trietylenethiophosphoramide, triaziquone, triethylennemelamine); alkylating-like agents (e.g., carboplatin (branded/marketed as PARAPL-ATIN®, cisplatin, oxaliplatin, nedaplatin, triplatin tetranitrate, satraplatin, picoplatin); nonclassical DNA crosslinkers (e.g., procarbazine, dacarbazine, temozolomide (branded/marketed as TEMODAR®), altretamine, mitomycin); and intercalating agents (e.g., actinomycin, bleomycin, mitomycin, chlorambucil, and plamycin).

[0116] Non-limiting examples of other therapies that may be administered to a subject in combination with a Compound include:

[0117] (1) a statin such as lovastatin (e.g., branded/marketed as MEVACOR®);
[0118] (2) an mTOR inhibitor such as sirolimus which is also known as Rapamycin (e.g., branded/marketed as RAPAMUNE®), temsirolimus (e.g., branded/marketed as TORISEL®, everolimus (e.g., branded/marketed as AFINITOR®), and deforolimus;
[0119] (3) a farnesy transferase inhibitor agent such as tipifarnib;
[0120] (4) an antifibrotic agent such as pirfenidone;
[0121] (5) a pegylated interferon such as PEG-interferon alfa-2b;
[0122] (6) a CNS stimulant such as methylphenidate (branded/marketed as RITALIN®);
[0123] (7) a HER-2 antagonist such as anti-HER-2 antibody (e.g., trastuzumab) and kinase inhibitor (e.g., lapatinib);
[0124] (8) an IGF-1 antagonist such as an anti-IGF-1 antibody (e.g., AVE1642 and IMC-A11) or an IGF-1 kinase inhibitor;
[0125] (9) EGFR/HER-1 antagonist such as an anti-EGFR antibody (e.g., cetuximab, panitumumab) or EGFR kinase inhibitor (e.g., erlotinib, gefitinib);
[0126] (10) SRC antagonist such as bosutinib;
[0127] (11) cyclin-dependent kinase (CDK) inhibitor such as selicidib;
[0128] (12) Janus kinase 2 inhibitor such as lestaurtinib;
[0129] (13) proteasome inhibitor such as bortezomib;
[0130] (14) phosphodiesterase inhibitor such as anagrelide;
[0131] (15) inosine monophosphate dehydrogenase inhibitor such as tiazofurine;
[0132] (16) lipoygenase inhibitor such as masproco led;
[0133] (17) endothelin antagonist;
[0134] (18) retinoid receptor antagonist such as tretinoin or aistretinoin;
[0135] (19) immune modulator such as lenalidomide, pomalidomide, or thalidomide;
[0136] (20) kinase (e.g., tyrosine kinase) inhibitor such as imatinib, dasatinib, erlotinib, nilotinib, gefitinib, sorafenib, sunitinib, lapatinib, or 1G100801;
[0137] (21) non-steroidal anti-inflammatory agent such as celecoxib (branded/marketed as CELEBREX®);
[0138] (22) human granulocyte colony-stimulating factor (G-CSF) such as filgrastim (branded/marketed as NEUPOGEN®);
[0139] (23) folic acid or leucovorin calcium;
[0140] (24) integrin antagonist such as an integrin α5β1 antagonist (e.g., JSMD627);
[0141] (25) nuclear factor kappa beta (NF-κβ) antagonist such as OT-551, which is also an anti-oxidant.
REFERENCES


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gecticagctt tatagctgca aacgctgtca aagtgaataa ttcttgttgg cagggataaa 190
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<400> SEQUENCE: 20

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Val Phe Phe Ser Thr Ser Gln Phe Gly Gly Ala Ala Pro Thr Phe Gly
35      40     45
Asp Thr Ser Thr Gly Thr Leu Gln Asp Ala Phe Asp Leu Asp Ala Leu
50   55     60
Lys Ala Leu Asp Ile Val Thr Cys Gin Gly Gin Gly Tyr Thr Asn
65   70     75     80
Glu Ile Tyr Pro Lys Leu Arg Asp Ser Gly Trp Gln Gly Tyr Trp Ile
85    90    95
Asp Ala Ala Ser Thr Leu Arg Met Lys Asp Asp Ala Ile Ile Ile Leu
100 105   110
Asp Pro Val Asn Gin Val Ala Thr Asp Gly Leu Asn Asn Gly Val
115 120 125
Lys Thr Phe Val Gly Gly Asn Thr Val Ser Leu Met Leu Met Ser
130   135   140
Leu Gly Gly Leu Phe Ala His Asn Leu Val Asp Trp Val Ser Val Ala
145 150   155   160
Thr Tyr Gin Ala Ala Ser Gly Gly Ala Arg His Met Arg Glu Leu
165 170   175
Leu Thr Gin Met Gly Gin Leu Tyr Gin His Val Ala Asp Glu Leu Ala
180 185   190
Thr Pro Ser Ser Ala Ile Leu Asp Ile Gin Arg Lys Val Thr Ala Leu
195 200   205
Thr Arg Ser Gly Glu Leu Pro Val Asn Phe Gly Val Pro Leu Ala
210 215   220
Gly Ser Leu Ile Pro Thr Ile Asp Lys Gin Leu Asp Asn Gin Gly Gin Ser
225 230   235   240
Arg Glu Glu Trp Lys Gin Gin Ala Glu Thr Asn Lys Ile Leu Asn Thr
245 250   255
Ala Ser Val Ile Pro Val Asp Gly Leu Cys Val Arg Val Gly Ala Leu
260   265   270
Arg Cys His Ser Gin Ala Phe Thr Ile Lys Leu Lys Gly Val Ser
275 280   285
Ile Pro Thr Val Glu Gin Leu Leu Ala Ala His Asn Pro Thr Ala Lys
290 295   300
Val Val Pro Asn Arg Arg Asp Ile Thr Met Arg Glu Leu Thr Pro Ala
305   310 315   320
Ala Val Thr Gly Thr Leu Thr Thr Pro Val Gly Arg Leu Arg Lys Leu
325 330   335
Asn Met Gly Pro Phe Leu Ser Ala Phe Thr Val Gly Arg Leu Arg Gin Leu
340 345   350
Leu Trp Gly Ala Ala Glu Pro Leu Arg Arg Met Leu Arg Gin Leu Ala
355 360   365

<210> SEQ ID NO: 21
<211> LENGTH: 60
What is claimed is:
1. A method of making modified facultative anaerobic gram-negative bacteria into an obligate anaerobe, wherein said facultative anaerobic gram-negative bacteria comprise a strictly hypoxia regulated essential gene expressing cassette, and said obligate anaerobe inhibits and reduces the growth of a solid tumor cancer when administered in vivo.
2. A method of making modified facultative anaerobic gram-negative bacteria into an obligate anaerobe, wherein said facultative anaerobic gram-negative bacteria are Salmonella sp.
3. The method of claim 1, wherein the condition of the obligate anaerobe is diaminopimelic acid (DAP).
4. The method of claim 1, wherein the essential gene is asd or dapA.
5. The method of claim 1, wherein the strictly hypoxia regulated cassette contains a forward anaerobic inducible promoter, an essential gene, and a reverse aerobic promoter.
6. The method of claim 5, wherein the forward anaerobic inducible promoter is pcpP, ansB or fisF.
7. The method of claim 5, wherein the reverse aerobic promoter is sodA.
8. The method of claim 5, wherein the strictly hypoxia regulated essential gene expressing cassette is chromosome-based.
9. The method of claim 1, wherein the solid tumor cancer is breast cancer, liver cancer, lung cancer, melanoma, colon carcinoma, kidney cancer, prostate cancer, neuroblastoma, or bladder cancer.
10. The method of claim 1, wherein the cancer is breast cancer, liver cancer or neuroblastoma.
11. The method of treating cancer using a modified bacteria comprising a strictly hypoxia regulated essential gene expressing cassette.
12. The method of claim 11 further comprising a treatment in combination with a second cancer therapy.
13. The method of claim 2, wherein said bacteria are Salmonella typhi.
14. The method of claim 2, wherein said facultative anaerobic gram-negative bacteria are Salmonella typhimurium.
15. The method of claim 2, wherein said facultative anaerobic gram-negative bacteria are Salmonella choleraesuis.
16. The method of claim 2, wherein said facultative anaerobic gram-negative bacteria are Salmonella enteritidis.
17. The method of claim 1, wherein the facultative anaerobic gram-negative bacteria are Escherichia coli.
18. The method of claim 17, wherein said facultative anaerobic gram-negative bacteria are Escherichia coli K-12.
19. The method of claim 17, wherein said facultative anaerobic gram-negative bacteria are Escherichia coli O157:H7.
20. The method of claim 1, wherein the facultative anaerobic gram-negative bacteria are Shigella.
21. The method of claim 20, wherein said facultative anaerobic gram-negative bacteria are Shigella dysenteriae.
22. The method of claim 20, wherein said facultative anaerobic gram-negative bacteria are Shigella flexneri.
23. The method of claim 20, wherein said facultative anaerobic gram-negative bacteria are Shigella boydii.
24. The method of claim 20, wherein said facultative anaerobic gram-negative bacteria are Shigella sonnei.
25. The method of claim 1, wherein the facultative anaerobic gram-negative bacteria are Yersinia.
26. The method of claim 25, wherein said facultative anaerobic gram-negative bacteria are Yersinia pestis.
27. The method of claim 25, wherein said facultative anaerobic gram-negative bacteria are Yersinia pseudotuberculosis.
28. The method of claim 25, wherein said facultative anaerobic gram-negative bacteria are Yersinia enterocolitica.
29. The method of claim 12, wherein the second cancer therapy is treatment with 5Fluorouracil (5-FU).
30. A vector comprising: (a) a hypoxia condition promoter comprising an inducer binding site that is operatively linked to an essential gene; and (b) optionally further comprises an antisense promoter that is negatively regulated by the inducer.
31. The vector of claim 30, wherein the inducer binding site is FNR binding site.
32. The vector of claim 30, wherein the condition promoter is responsive to diaminopimelic acid (DAP).
33. The vector of claim 30, wherein the essential gene is asd or dapA.
34. The vector of claim 30, wherein the hypoxia condition promoter is pcpP, ansB or fisF.
35. The vector of claim 30, wherein the antisense promoter is sodA.
36. A bacteria comprising the vector of claim 30.
37. The bacteria of claim 36, wherein the bacteria are Salmonella sp.
38. The bacteria of claim 37, wherein said bacteria are Salmonella typhi.
39. The bacteria of claim 37, wherein said bacteria are Salmonella typhimurium.
40. The bacteria of claim 37, wherein said bacteria are Salmonella choleraesuis.
41. The bacteria of claim 37, wherein said bacteria are Salmonella enteritidis.
42. The bacteria of claim 36, wherein said bacteria are Escherichia coli.
43. The bacteria of claim 42, wherein said bacteria are Escherichia coli K-12.
44. The bacteria of claim 42, wherein said bacteria are Escherichia coli O157:H7.
45. The bacteria of claim 36, wherein said bacteria are Shigella.
46. The bacteria of claim 45, wherein said bacteria are Shigella dysenteriae.
47. The bacteria of claim 45, wherein said bacteria are Shigella flexneri.
48. The bacteria of claim 45, wherein said bacteria are Shigella boydii.
49. The bacteria of claim 45, wherein said bacteria are *Shigella sonnei*.

50. The bacteria of claim 36, wherein said bacteria are *Yersinia*.

51. The bacteria of claim 50, wherein said bacteria are *Yersinia pestis*.

52. The bacteria of claim 50, wherein said bacteria are *Yersinia pseudotuberculosis*.

53. The bacteria of claim 50, wherein said bacteria are *Yersinia enterocolitica*.

54. A method of treating cancer/tumor using the bacteria of claim 36, wherein the cancer/tumor is a cancer/tumor of the breast, liver, lung, skin, carcinoma, kidney, prostate, nervous system, or bladder.

55. The method of claim 54 further comprising a treatment in combination with a second cancer therapy.

56. The method of claim 55, wherein the second cancer therapy is treatment with 5-FU.

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