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Treating malignant tumors with high field strength electroporation of plasmids encoding IL-12

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Heller et al.

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(45) **Date of Patent:** **Sep. 27, 2011**

(54) **TREATING MALIGNANT TUMORS WITH
HIGH FIELD STRENGTH
ELECTROPORATION OF PLASMIDS
ENCODING IL-12**

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patent is extended or adjusted under 35
U.S.C. 154(b) by 751 days.

(21) Appl. No.: **11/164,626**

(22) Filed: **Nov. 30, 2005**

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PCT/US2004/017153, filed on Jun. 1, 2004.

(60) Provisional application No. 60/320,239, filed on May
30, 2003.

(51) **Int. Cl.**
A61K 48/00 (2006.01)
C12N 15/87 (2006.01)

(52) **U.S. Cl.** **514/44 R; 435/461**

(58) **Field of Classification Search** None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,593,130	B1	7/2003	Sen et al.	
6,697,669	B2 *	2/2004	Dev et al.	604/21
6,972,013	B1 *	12/2005	Zhang et al.	604/501
7,412,284	B2 *	8/2008	Hofmann	604/21
2003/0018006	A1 *	1/2003	Tao et al.	514/44

OTHER PUBLICATIONS

Heller, et al. (1999) Clinical Applications of Electrotherapy,
Advanced Drug Delivery Reviews, 35(2): 119-29.*
Andre, et al. (2004) Gene Therapy, 11: S33-S42.*

Miklavcic, et al. (2004) Electroporation for electrochemotherapy and
gene therapy. In: P.J. Rosch and M.S. Markov, Editors,
Bioelectromagnetic Medicine, Marcel Dekker, New York, pp. 637-
656.*

Heller et al., In Vivo Electroporation of Plasmids Encoding GM-CSF
or Interleukin-2 into Existing B16 Melanomas Combined with
Electrochemotherapy Indices Long-Term . . . Melanoma Research,
2000, vol. 10, pp. 577-583.

Lee et al., Inhibition of Established Subcutaneous and Metastatic
Murine Tumors by Intramuscular Electroporation of the Interleukin-
12 Gene, Journal of Biomedical Science, Biomedical Science, 2003,
vol. 10, pp. 73-88.

Yamashita et al., Electroporation-Mediated Interleukin-12 Gene
Therapy for Hepatocellular Carcinoma in the Mice Model, Cancer
Research 61, 1005-1012, Feb. 1, 2001.

Kishida et al., Electrochemo-Gene Therapy of Cancer: Intratumoral
Delivery of Interleukin-12 Gene and Bleomycin Synergist Induced
Therapeutic Immunity and Suppressed . . . Molecular Therapy, 2003,
vol. 8, No. 5, pp. 738-745.

Mir et al., High-Efficiency Gene Transfer Into Skeletal Muscle Medi-
ated by Electric Pulses, PNAS, vol. 96, Issue 8, 4262-4267, Apr. 13,
1999.

Lohr et al., Effective Tumor Therapy with Plasmid-Encoded
Cytokines Combined with In Vivo Electroporation, Cancer Research
61, 3281-3284, Apr. 15, 2001.

Lucas et al., IL-12 Plasmid Delivery by In Vivo Electroporation for
the Successful Treatment of Established Subcutaneous B16.F10
Melanoma, Molecular Therapy, vol. 5, No. 6, Year 2002, pp. 668-675.

Lucas et al., IL-12 Gene Therapy Using an Electronically Mediated
Nonviral Approach Reduces Metastatic Growth of Melanoma, DNA
and Cell Biology, vol. 22, No. 12, 2003.

* cited by examiner

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Hopen, P.A.

(57) **ABSTRACT**

In accordance with the present invention is provided a method
of treating a subject having a cancerous tumor. The treatment
protocol methodology includes injecting the cancerous tumor
with an effective dose of plasmid coding for a therapeutic
protein followed by administering electroporation therapy to
the tumor, the electroporation therapy includes the adminis-
tration of at least one high voltage, short duration pulse to the
tumor.

18 Claims, 12 Drawing Sheets
(3 of 12 Drawing Sheet(s) Filed in Color)

FIG. 1

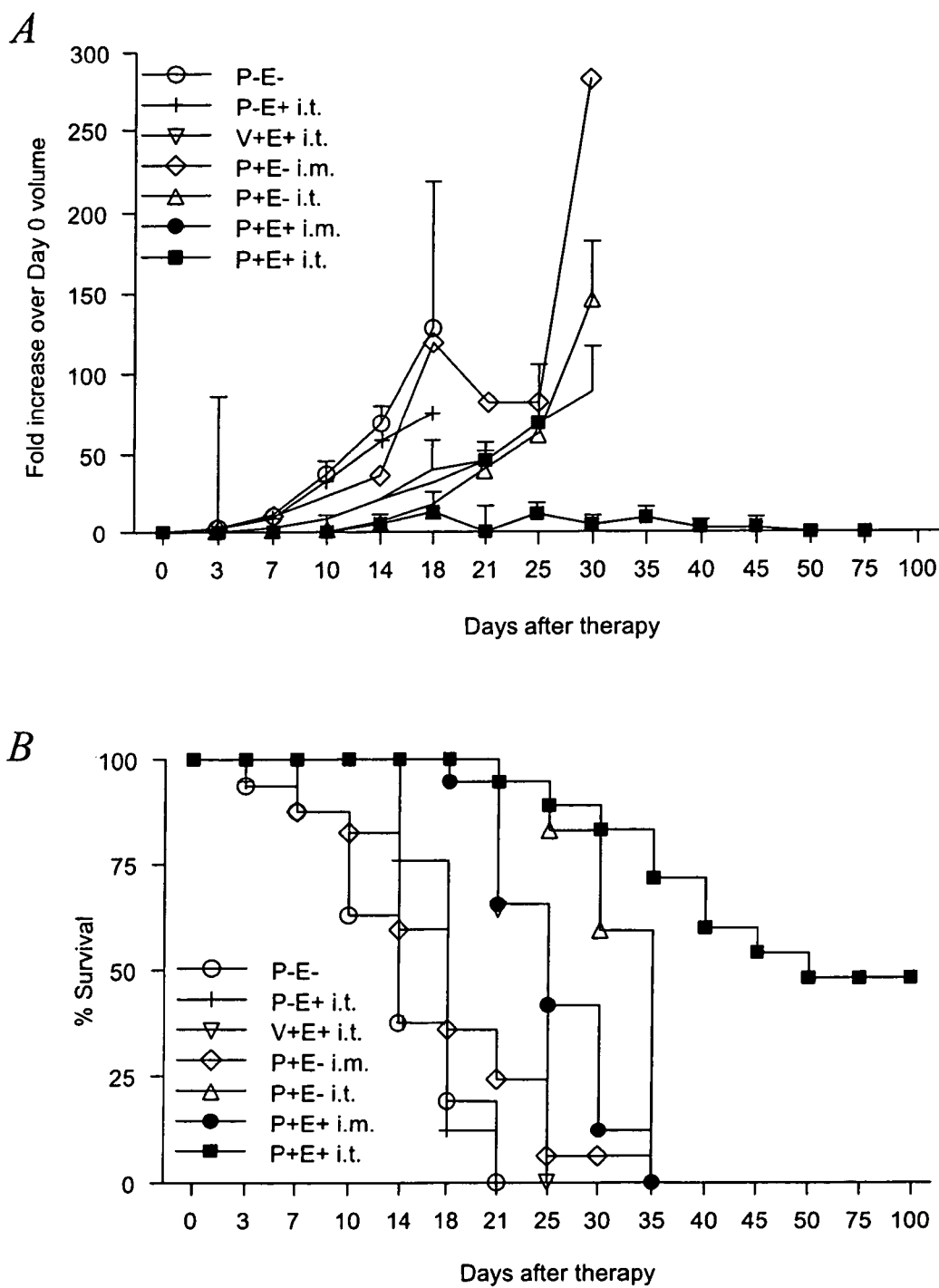


FIG. 2

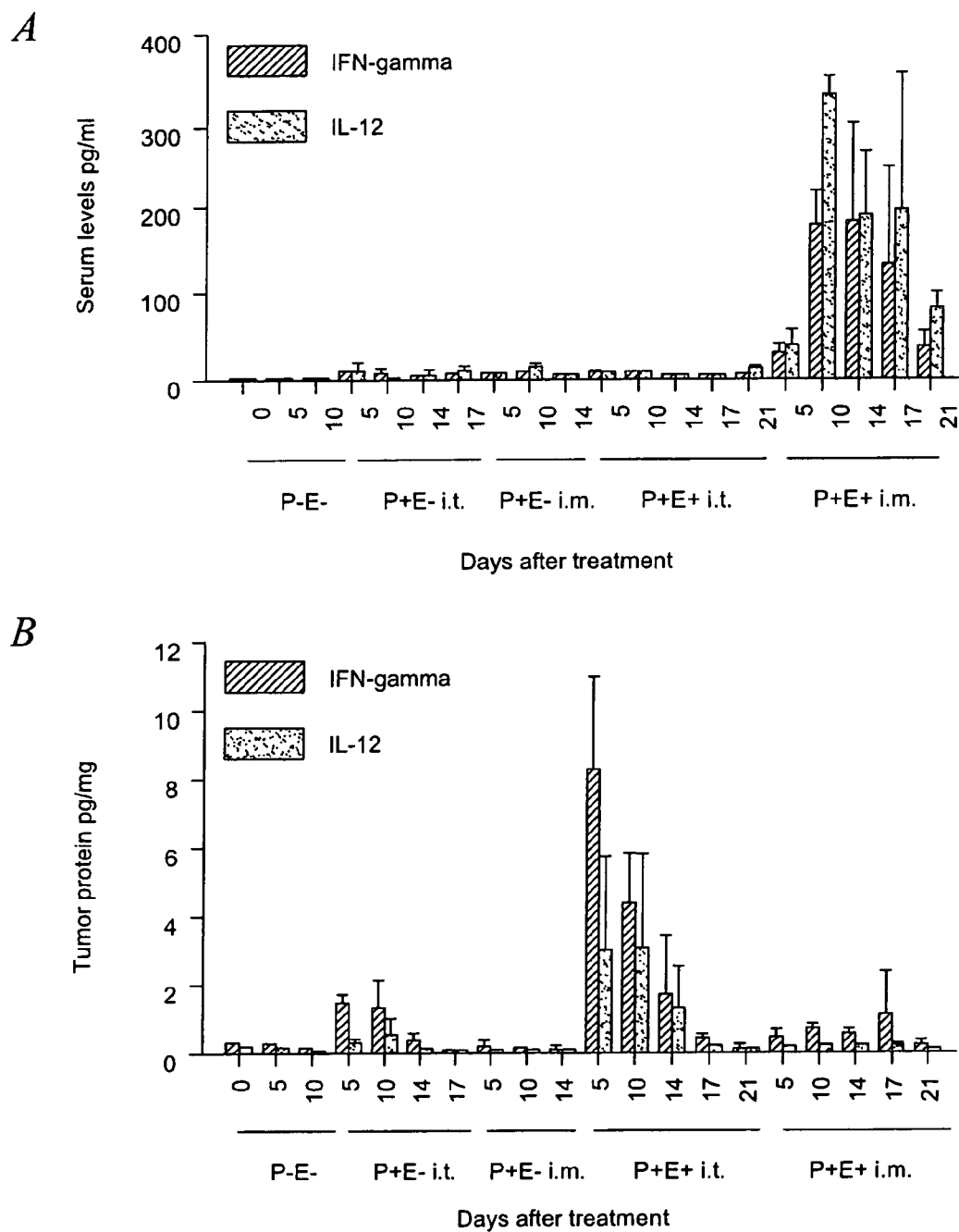


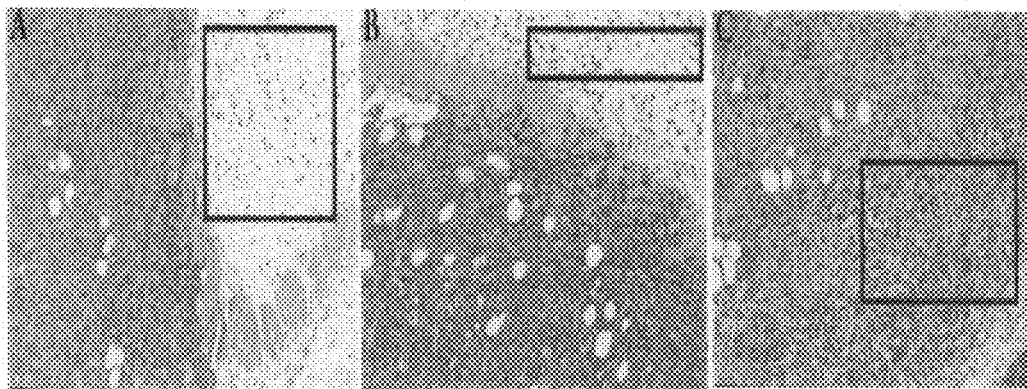
FIG. 3

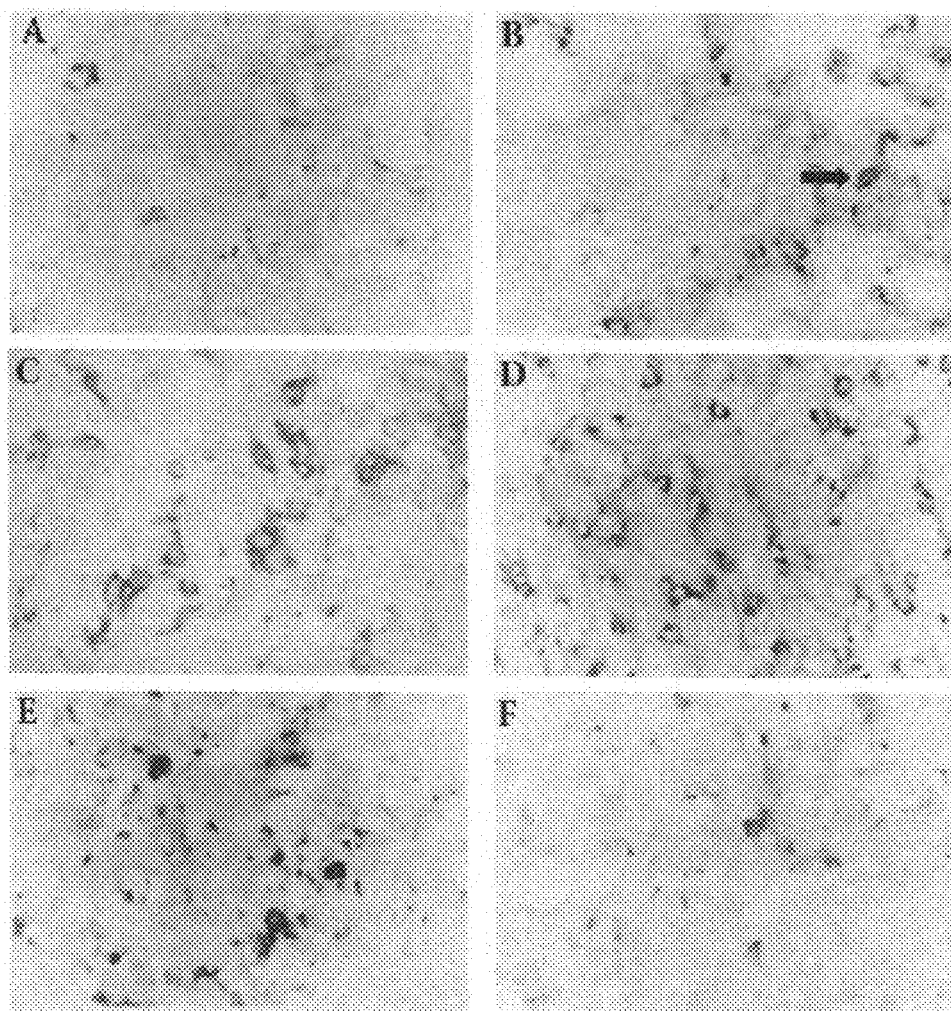
FIG. 4

FIG. 5

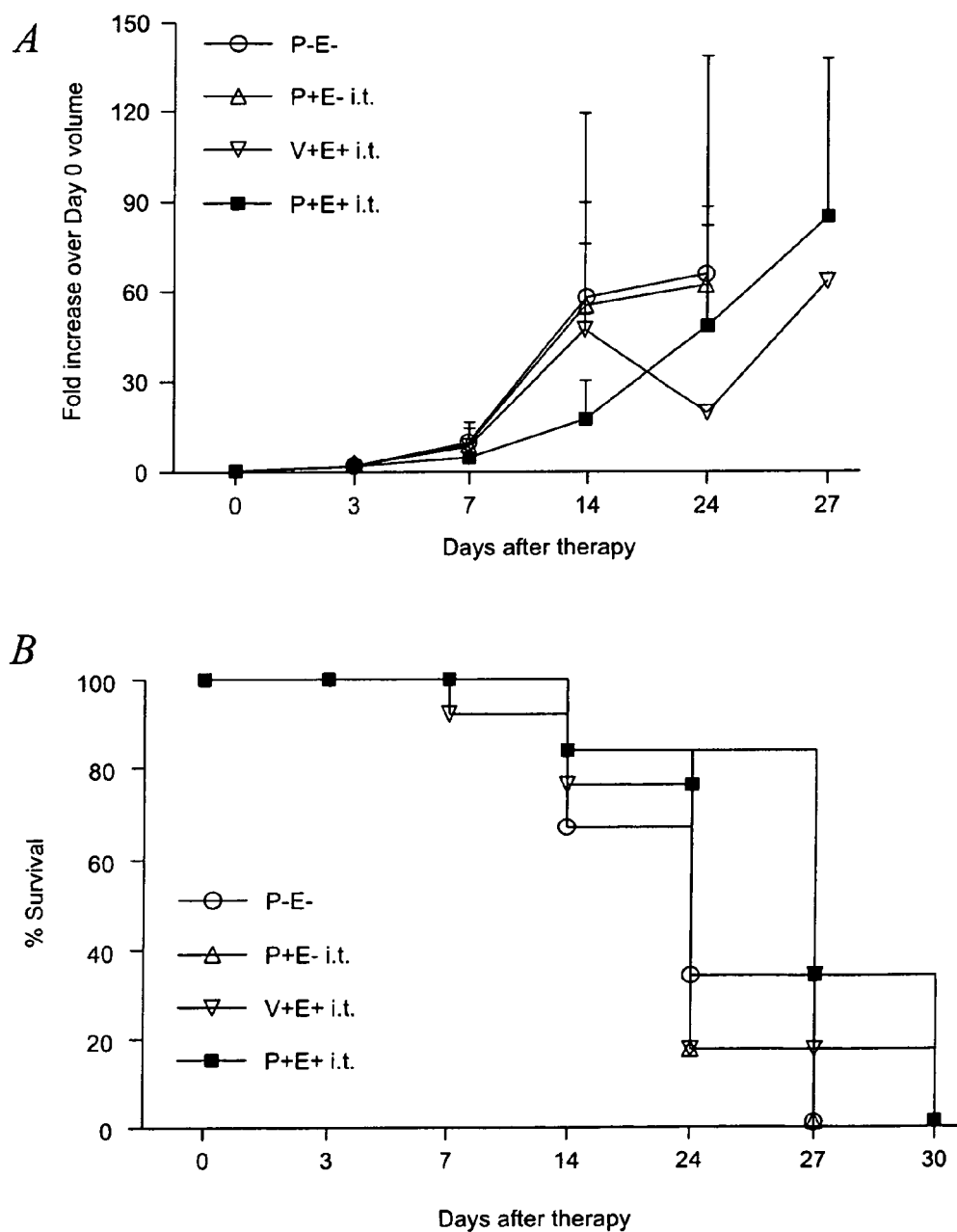


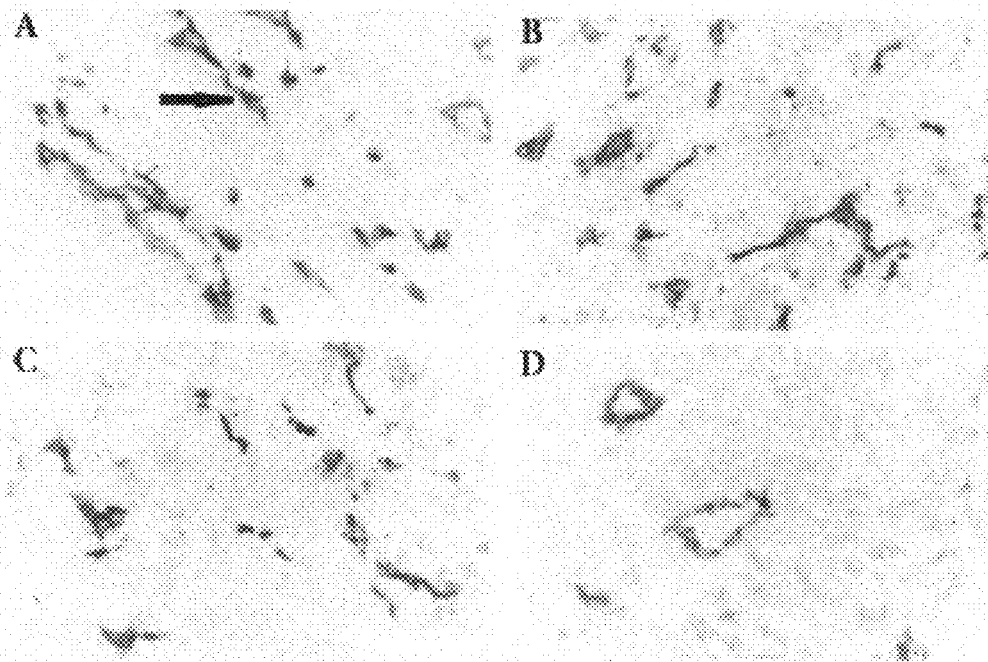
FIG. 6.

Fig. 7

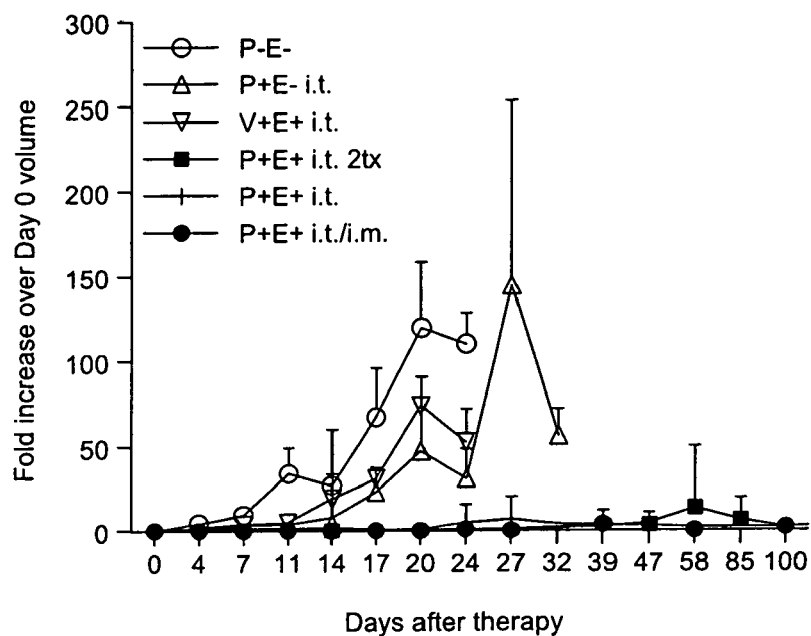
TABLE 1: Tumor blood vessel counts from C57BL/6 mice in each treatment group

	P-E-	P-E- i.t.	P+E- i.m.	V+E+ i.t.	P+E+ i.m.	P+E+ i.t.
Tumor 1	24	10	27	20	17	6
Tumor 2	32	21	32	28	38	12
Tumor 3	49	28	39	39	38	18

P-, No plasmid; E-, no electroporation; P+, pIRES-IL-12; E+, electroporation; V+, control plasmid, pND2Lux; i.t., Intratumoral; i.m., Intramuscular.

FIG. 8

A



B

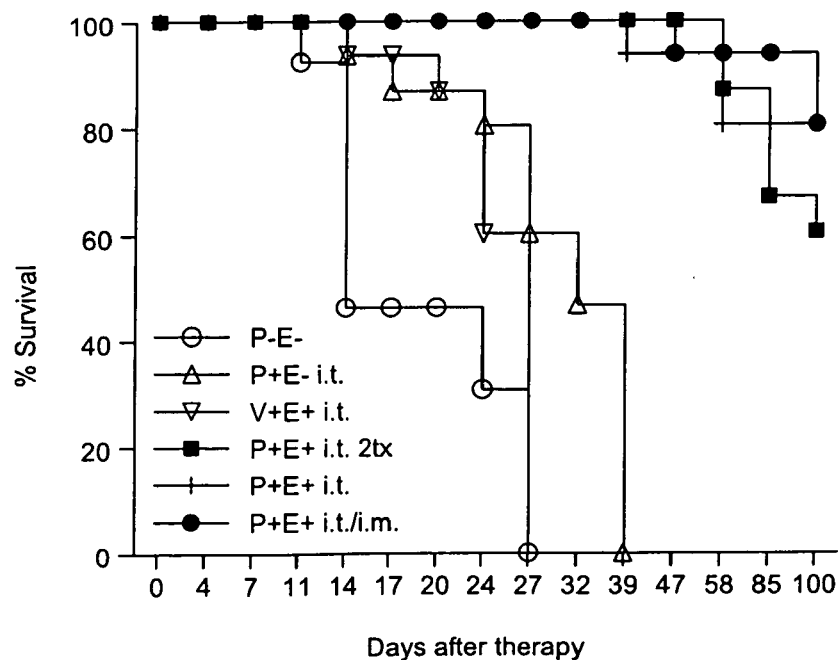
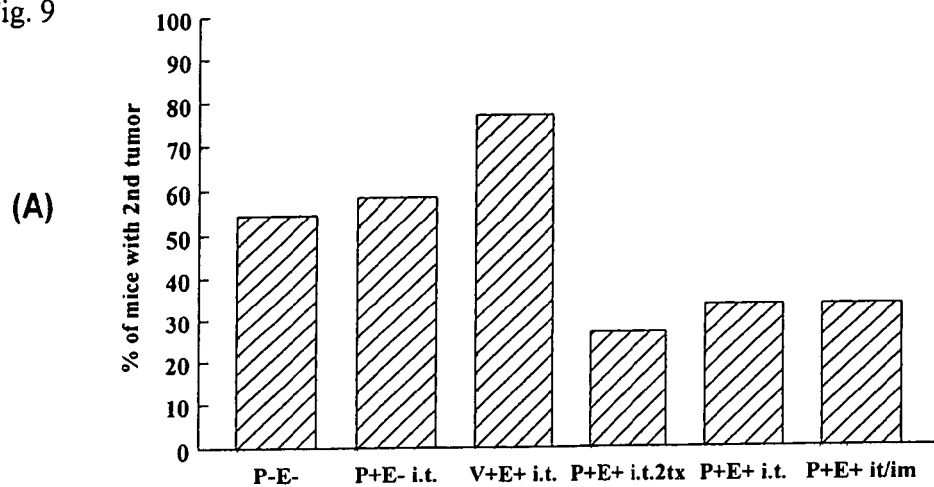


Fig. 9



(B)

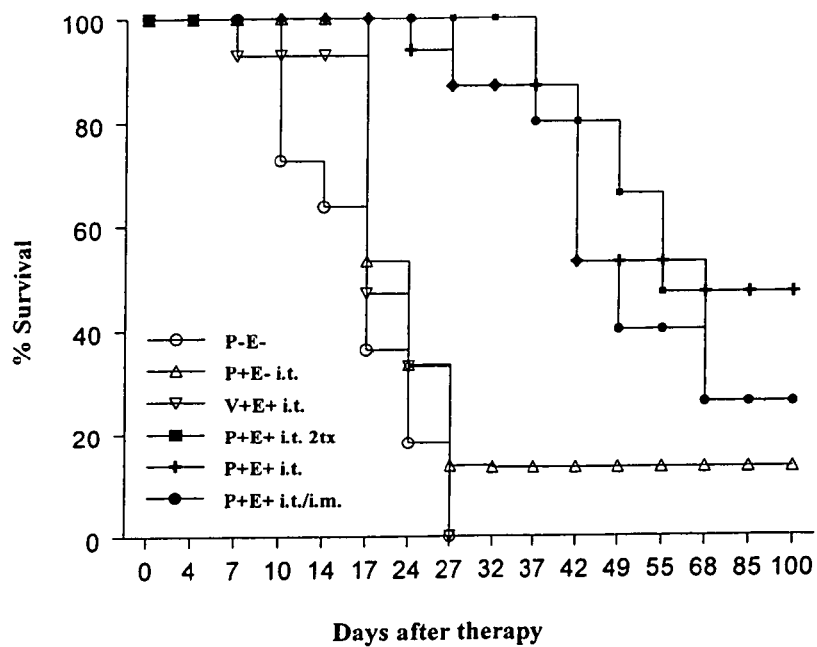


Fig. 10

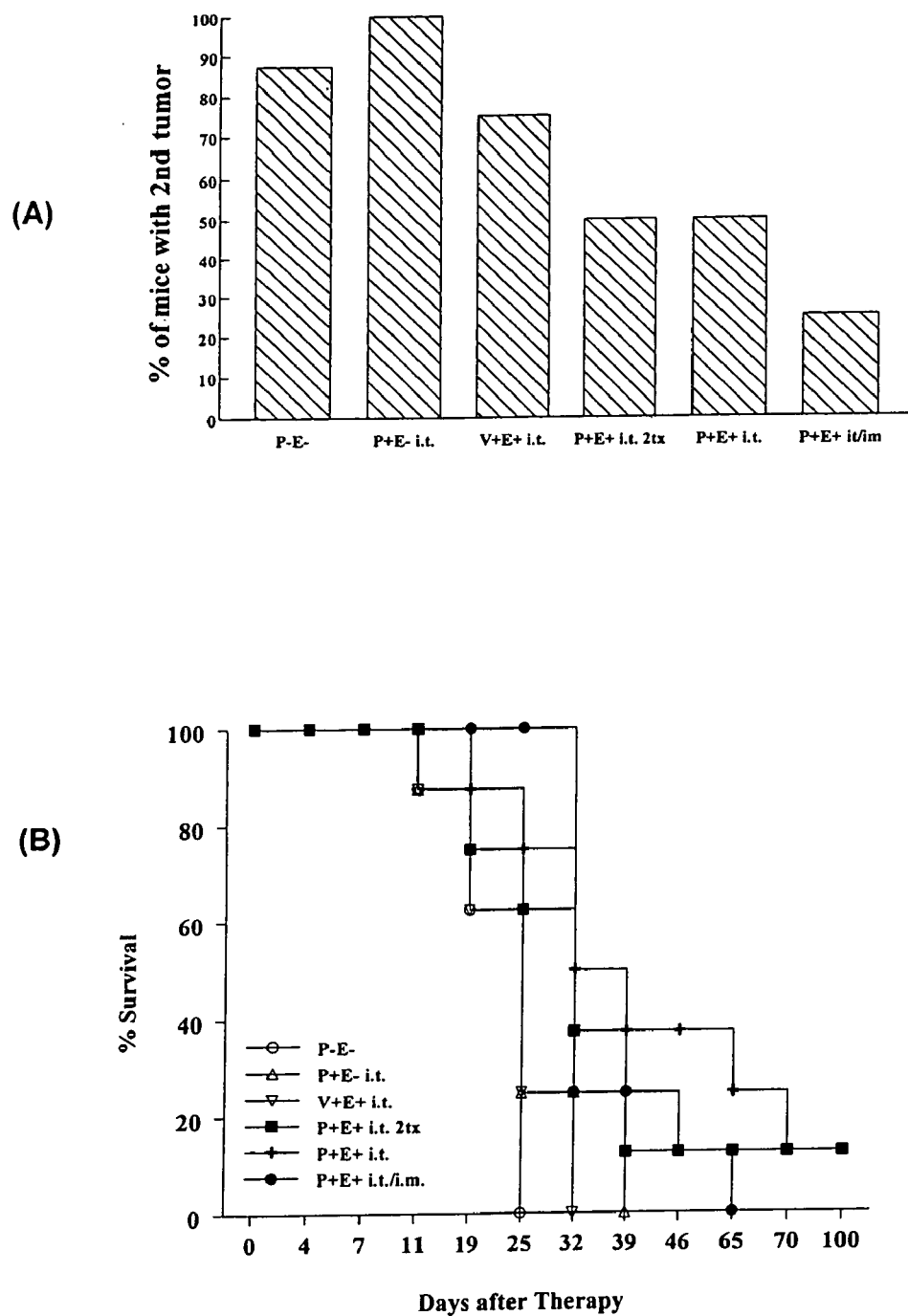
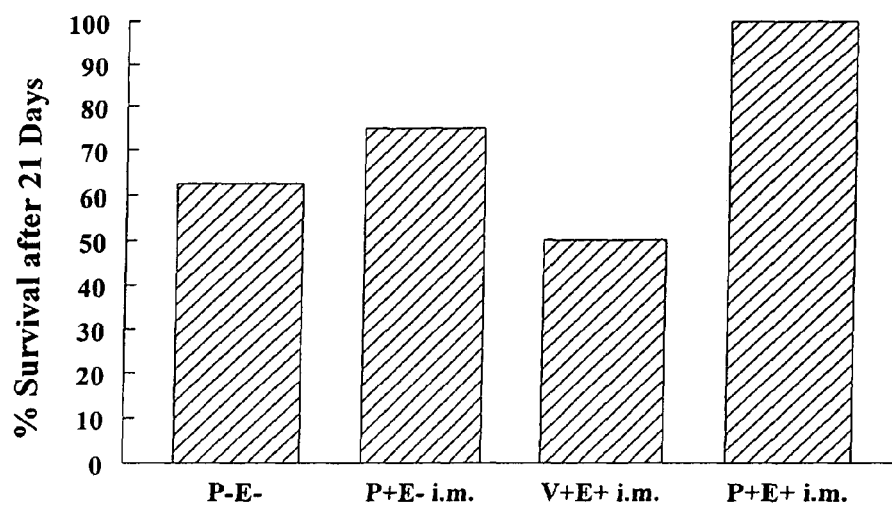


Fig. 11

	P-E-	V+E+	P+E-	P+E+
Number of lung tumor	0	0	0	0
nodules in each mouse	3	0	0	0
per treatment group.	8	4	2	0
	10	4	3	0
	16	13	6	0
	32	14	20	1
	45	18	30	1
	50	35	40	40

Fig. 12



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TREATING MALIGNANT TUMORS WITH HIGH FIELD STRENGTH ELECTROPORATION OF PLASMIDS ENCODING IL-12

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of International Patent Application No. PCT/US2004/017153, filed on Jun. 1, 2004, which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/320,239 filed May 30, 2003.

BACKGROUND OF INVENTION

The effective treatment of metastases is a challenge for any cancer treatment. For immunotherapy to be beneficial in the treatment of metastatic disease, the immune system must recognize tumor cells throughout the body, which can be achieved by inducing a systemic immune response or through the creation of memory T cells following recognition of a primary tumor.

Many cytokines have been intensively investigated as potential anticancer agents. Among the many cytokines evaluated, Interleukin-12 (IL-12) has been shown to exhibit strong antitumor activities. IL-12 can upregulate the proliferation and maturation of T cells and natural killer (NK) cells, induce production of IFN- γ , inhibit angiogenesis, and upregulate expression of accessory molecules such as HLA. Unfortunately, delivery of IL-12 in the form of recombinant protein results in severe toxicity and adverse side effects, including death. Therefore, gene therapy strategies for delivery of IL-12 have been explored such as the use of viral vectors, gene gun, microspheres, direct injection of plasmid, and electroporation.

The antitumor potential of IL-12 has been reported in numerous immunotherapy studies. The proposed antitumor mechanisms of IL-12 include effects on the immune system such as the induction of IFN- γ , upregulation of T cells, and proliferation of natural killer (NK) cells. In addition, IL-12 inhibits angiogenesis, the formation of new blood vessels. This wide range of effects on the immune system as well as antiangiogenic properties results in a potentially potent antitumor treatment. Unfortunately, preclinical and clinical trials using systemic administration of recombinant IL-12 demonstrated potential adverse side effects. Administration of recombinant IL-12 locally or systemically has been reported to induce potent antitumor activity in a variety of murine tumor models, causing regression of established tumors. However, in these studies, repeated delivery of recombinant IL-12 on a daily basis was required to achieve the maximal therapeutic activity, and was also usually associated with a dose-dependent toxicity. The use of gene therapy for the delivery of IL-12, by gene gun, resulted in fewer side effects than recombinant protein therapy. Several studies using viral and nonviral gene delivery techniques have reported success in slowing and/or preventing tumor growth. However, these studies have had limited success in demonstrating complete regression of the poorly immunogenic B16.F10 melanoma and subsequent resistance to challenge.

In vivo electroporation is a gene delivery technique that has been used successfully for efficient delivery of plasmid DNA to many different tissues. Studies have reported the administration of in vivo electroporation for delivery of plasmid DNA to B16 melanomas and other tumor tissues. Although systemic administration of recombinant IL-12 revealed its antitumor potential, expression of IFN- γ at the tumor site

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has been shown to be critical for successful tumor regression. Systemic and local expression of a gene or cDNA encoded by a plasmid can be obtained with administration of in vivo electroporation. Use of in vivo electroporation enhances plasmid DNA uptake in tumor tissue, resulting in expression within the tumor, and delivers plasmids to muscle tissue, resulting in systemic cytokine expression.

It has been shown that electroporation can be used to transfect cells in vivo with plasmid DNA. Recent studies have shown that electroporation is capable of enhancing delivery of plasmid DNA as an antitumor agent. Electroporation has been administered for treatment of hepatocellular carcinomas, adenocarcinoma, breast tumors, squamous cell carcinoma and B16.F10 melanoma in rodent models. The B16.F10 murine melanoma model has been used extensively for testing potential immunotherapy protocols for the delivery of IL-12 and other cytokines either as recombinant protein or by gene therapy.

Its wide range of effects on the immune system and its antiangiogenic properties make IL-12 an excellent candidate for use as an immunotherapeutic agent. Because of its potential toxicity, it is important to give careful consideration to the delivery method of IL-12. In vivo electroporation is a safe, nontoxic delivery system and has been used for efficient delivery of chemotherapeutic agents and plasmid DNA, including plasmids encoding IL-12.

Electroporation mediated in vivo delivery of the murine interleukin-12 (IL-12) gene in an expression plasmid has been shown to provide antitumor and antimetastasis activity. Various protocols are known in the art for the delivery of plasmid encoding IL-12 utilizing in vivo electroporation for the treatment of cancer. The protocols known in the art describe in vivo electroporation mediated cytokine based gene therapy, both intratumor and intramuscular, utilizing low-voltage and long-pulse currents. Prior art methods have identified these low-voltage levels to be less than 300V and long pulses to be in the area of 50 ms. Rationalization for the use of low-voltage levels and long pulse lengths for the delivery of plasmid encoding IL-12 for the treatment of tumors is based on well-known principles of electroporation and electrochemotherapy. It is known that electric pulses with moderate electric field intensity can cause temporary cell membrane permeabilization, which may then lead to rapid genetic transformation and manipulation in a wide variety of cell types including bacteria, yeasts, animal and human cells, and so forth. Conversely, electric pulses with high electric field intensity can cause permanent cell membrane breakdown and tissue damage. All prior art methods describing the administration of an electroporation protocol for delivery of IL-12 to the target tissue are based on the application of low-voltage, long length pulses. These treatment protocols known in the art have not been effective in demonstrating acceptable cure rates for tumors, including B16.F10 melanoma tumors. Additionally, the known treatment protocols have been unable to demonstrate improved long-term subject survival rates.

Accordingly, what is needed in the art is an electroporation protocol for the delivery of a plasmid encoding a therapeutic protein, such as IL-12, that will provide substantially improved results in the regression of cancer tumors, such as melanoma, while also substantially improving the long-term survival rates.

SUMMARY OF INVENTION

The present invention provides a method for the treatment of malignancies, wherein the administration of a plasmid encoding for a therapeutic protein in combination with elec-

troporation has a therapeutic effect on primary tumors as well as distant tumors and metastases.

According to one embodiment of the invention, a method of treating a subject having a cancerous tumor is provided, the method includes injecting the cancerous tumor with an effective dose of plasmid coding for a therapeutic protein and administering electroporation therapy to the tumor. The electroporation therapy further includes the administration of at least one high voltage pulse having a short duration.

The method of the present invention is effective in the treatment of a variety of cancerous tumors, including melanoma. The data presented is an exemplary embodiment of the present invention for the treatment of B16.F10 melanoma in mice. However, the exemplary embodiment and data presented are not intended to limit the method of the present invention to the treatment of B16.F10 melanoma. The method of the present invention is applicable to the treatment of a variety of cancers, including those common to humans.

A variety of cytokines have been identified as being effective in the treatment of cancer. Interleukin 12 (IL-12) is a cytokine that has been studied extensively as an antitumor agent. In a particular embodiment of the present invention, the plasmid coding for a therapeutic protein administered to subject is a plasmid coding for IL-12. Other effective cytokines are within the scope of the present invention.

The electroporation therapy administered in accordance with the present invention is characterized by high voltages pulses of short duration. In accordance with the present invention, a high voltage pulse is defined to be greater than about 400V/cm. Additionally, in accordance with the present invention a short duration pulse is defined to be less than about 1 millisecond.

In a particular embodiment, the electroporation therapy administered to the subject tumor includes at least one high voltage pulse of about 1500V/cm having a duration of about 100 microseconds.

In an additional embodiment, the method of the present invention further includes the step of injecting an effective dose of plasmid encoding for a therapeutic protein into the muscle tissue of the subject and administering electroporation to the subject intramuscularly using at least one low voltage pulse having a long pulse width. The plasmid encoding for a therapeutic protein used in this step may be a plasmid encoding for IL-12, or any other effective plasmid.

In a particular embodiment of the intramuscular electroporation therapy step, the voltage level is a voltage of about 100V/cm and the pulse duration is about 20 milliseconds.

An increase in the effectiveness of the treatment has been observed when the treatment method of the present invention is administered multiple times. In this instance, a method of treating a subject having a cancerous tumor, is provided which includes injecting the cancerous tumor with a first effective dose of plasmid coding for a therapeutic protein, administering a first electroporation therapy to the tumor, the first electroporation therapy further comprising the administration of at least one high voltage pulse having a short duration, then subsequently injecting the cancerous tumor with a second effective dose of plasmid coding for a therapeutic protein, and administering a second electroporation therapy to the tumor, the second electroporation therapy further comprising the administration of at least one high voltage pulse having a short duration. Additionally, a third effective dose of plasmid coding for a therapeutic protein and a third electroporation therapy may be administered to the tumor, the third electroporation therapy further comprising the administration of at least one high voltage pulse having a short duration. This two or three step process may be followed by the step of

injecting an effective dose of plasmid encoding for a therapeutic protein into the muscle tissue of the subject and administering electroporation to the subject intramuscularly using at least one low voltage pulse having a long pulse width.

A plurality of high voltage, short pulse duration electroporation therapy conditions are within the scope of the present invention. In an exemplary embodiment, the method of the present invention includes injecting a cancerous tumor with a first effective dose of plasmid coding for IL-12, administering a first electroporation therapy to the tumor, the first electroporation therapy further comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration, injecting the cancerous tumor with a second effective dose of plasmid coding for IL-12, administering a second electroporation therapy to the tumor, the second electroporation therapy further comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration, injecting the cancerous tumor with a third effective dose of plasmid coding IL-12, and administering a third electroporation therapy to the tumor, the third electroporation therapy further comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration. Additionally, the method may include injecting an effective dose of plasmid encoding for a therapeutic protein into the muscle tissue of the subject, administering electroporation to the subject intramuscularly using 12 pulses delivered at 100V/cm of 20 milliseconds in duration.

In an exemplary embodiment of the present invention, a method for the treatment of malignancies is provided wherein the method includes administering a first treatment on day zero, the first treatment comprising injecting the cancerous tumor with a first effective dose of plasmid coding for IL-12 and administering a first electroporation therapy to the tumor, the first electroporation therapy further comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration. On day four a second treatment is administered comprising injecting the cancerous tumor with a second effective dose of plasmid coding for IL-12 and administering a second electroporation therapy to the tumor, the second electroporation therapy further comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration. On day seven a third treatment is administered, the third treatment comprising injecting the cancerous tumor with a third effective dose of plasmid coding IL-12 and administering a third electroporation therapy to the tumor, the third electroporation therapy further comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration. An additional step may include injecting an effective dose of plasmid encoding for IL-12 into the muscle tissue of the subject, administering electroporation therapy to the subject intramuscularly using twelve pulses delivered at 100V/cm at 20 millisecond duration.

As demonstrated by the results provided in the detailed description, the method of the present invention provides a treatment protocol for cancer resulting in a statistically significant improvement in survival rates over all other known methods in the art the utilize a plasmid coding for IL-12 and electroporation. The protocol of the present invention utilizes high voltage, short duration pulses. All other protocols known in the art for the delivery and expression of IL-12, utilize low voltage, long duration electroporation pulses. As such, the present invention results in new and unexpected results based on a novel protocol for the delivery of a plasmid coding for a protein and electroporation.

BRIEF DESCRIPTION OF THE DRAWINGS

The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application

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publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description, taken in connection with the accompanying drawings, in which:

FIG. 1 is a graphical illustration of the administration of plasmid DNA encoding IL-12 followed by electroporation results in complete tumor regression. (A) Fold increase over day 0 tumor volume following treatment. P, pIRES IL-12; V, control plasmid, pND2Lux; E, electroporation. Treatment mode of delivery: i.t., intratumor; i.m., intramuscular. A plus sign indicates treatment was administered; a minus sign indicates treatment was not administered. Initial treatment day is day 0; mice were treated again on day 7. Results for all groups (except P-E+ i.t. and V+E+ i.t.) represent the combined data from three replicate experiments, and error bars represent the standard error of the mean. The P-E+ i.t. and V+E+ i.t. treatment groups were tested in one experiment because existing data in our lab showed these treatments to be ineffectual. Error bars for these two groups represent standard deviation. The total number of samples for each treatment group are as follows: P-E-, n=16; P-E+ i.t. and V+E+ i.t., n=8; and for the remainder of groups, n=17. Mice were killed when tumor volume exceeded 1000 mm³. Data are expressed for surviving mice on each day. (B) Percentage survival of mice represented in (A). Mice either succumbed to disease or were killed when tumor volume exceeded 1000 mm³.

FIG. 2 is a graphical illustration of the results of the analysis of serum and tumor tissue for IL-12 and IFN- γ expression. P, pIRES IL-12; E, electroporation. Mode of delivery: i.t., intratumor; i.m., intramuscular. (A) Serum levels of IL-12 and IFN- γ in tumor-bearing mice. For each treatment group on each day tested, n=4 mice. Error bars represent standard deviation. (B) Mean tumor expression of IL-12 and IFN- γ . For each treatment group on each day tested, n=4 mice. Error bars represent standard deviation.

FIG. 3 is an illustration of representative sections of tumor tissue, 5 days after treatment, analyzed by H&E staining for infiltrating immune cells. Three sections per tumor were examined. All sections are shown at $\times 250$ magnification. An area containing immune cells is marked by a box. (A) No treatment. (B) Administration of IL-12 i.m. with electroporation. (C) Administration of IL-12 i.t. with electroporation.

FIG. 4 is an illustration of representative sections of tumor tissue, 5 days after treatment, analyzed by immunohistochemistry for the stained brown. An arrow in (B) points to a cell representative of positive staining. (A, B) Staining for CD4+ lymphocytes and CD8+ lymphocytes, respectively, from untreated tumors. (C, D) Staining for CD4+ lymphocytes and CD8+ lymphocytes, respectively, from tumors receiving i.t. injection of plasmid DNA encoding IL-12 followed by electroporation. (E, F) Staining for CD4+ lymphocytes and CD8+ lymphocytes, respectively, from tumors following i.m. administration of plasmid DNA encoding IL-12 with electroporation.

FIG. 5 is a graphical illustration of the administration of IL-12 followed by electroporation which does not result in tumor regression in a nude mouse model. (A) Fold increase over day 0 tumor volume following treatment. P, pIRES IL-12; V, control plasmid, pND2Lux; E, electroporation. Mode of delivery: i.t., intratumor. Initial treatment day is day 0; mice were treated again on day 7. The data represent two experiments each, with four mice in each group. Error bars represent standard deviation. Mice were killed when tumor volume exceeded 1000 mm³. Data are expressed for surviving mice on each day. (B) Percentage survival of mice represented in (A).

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Mice either succumbed to disease or were killed when tumor volume exceeded 1000 mm³.

FIG. 6 is an illustration of the immunohistochemical analysis of tumor tissue for the presence of blood vessels. Representative sections rich in vessels are depicted for each treatment. Three sections per tumor were examined. All sections are shown at $\times 400$ magnification. An arrow in (A) points to a representative blood vessel. (A) Presence of blood vessels within tumors on day 0, before treatment. (B) Untreated tumors on day 5. (C) Tumors on day 5 from mice receiving i.m. injection of plasmid DNA encoding IL-12 followed by electroporation. (D) Blood vessels on day 5 from mice receiving i.t. administration of plasmid DNA encoding IL-12 followed by electroporation.

FIG. 7 is a table illustrating the tumor blood vessel counts from C57BL/6 mice in each treatment group.

FIG. 8 is a graphical illustration of the three treatment protocol in accordance with the present invention. For the three treatment protocol, day 0 is the day of the initial treatment and mice were treated again on days 4 and 7. (A) Fold increase of tumor volume compared to tumor volume on day of first treatment. (B) Percent survival of mice following treatment. Results represent the combined data of three replicate experiments and error bars represent the standard error of the mean. The total number of samples for each treatment group was 50. Mice were euthanized when tumor volume exceeded 1000 mm³. For both (A) and (B), data is expressed for surviving mice on each day. P=pIRES IL-12; V=control plasmid, pND2Lux; E=electroporation. For location of treatment, i.t.=intratumor delivery; i.m.=intramuscular delivery.

FIG. 9 is a graphical illustration of the short-term prevention of second tumors in accordance with the present invention. Three treatments were administered on days 0, 4, and 7 and two treatments administered on days 0 and 7. (A) Percent of mice that had a tumor form on the right flank, which received no treatment. (B) Percent survival of mice following treatment; 5×10^5 B16.F10 cells were injected on the right flank on day 0, at a time that the established tumor on the left flank was treated. Mice were euthanized when tumor volume exceeded 1000 mm³. Data represents three replicate experiments with an n of 5 each. P=pIRES IL-12; V=control plasmid, pND2Lux; E=electroporation. For location of treatment, i.t.=intratumor delivery; i.m.=intramuscular delivery.

FIG. 10 is a graphical illustration of the prevention of second tumor induced prior to initiation of therapy. Three treatments were administered on days 0, 4, and 7 and two treatments administered on days 0 and 7. (A) Percent of mice that had a tumor form on the right flank, which received no treatment. (B) Percent survival of mice following treatment; 5×10^5 B16.F10 cells were injected on the right flank. Three days after cells were injected on the left flank. Mice were euthanized when tumor volume exceeded 1000 mm³. Data represents three replicate experiments with an n of 5 each. P=pIRES IL-12; V=control plasmid, pND2Lux; E=electroporation. For location of treatment, i.t.=intratumor delivery; i.m.=intramuscular delivery.

FIG. 11 is a table illustrating the results of a treatment with intramuscular administration of IL-12 by electroporation and how the treatment prevents development of tumor nodules in the lungs.

FIG. 12 is a graphical illustration of the survival rate of mice receiving a high dose of B16 cells intravenously. Three treatments were administered on days 0, 4, and 7. Mice were followed for 21 days and then euthanized. Data represents two replicate experiments with an n of 4 in each. Mice received an injection of 5×10^5 B16.F10 cells to the tail vein on

day 0, at the time of treatment by delivering plasmid intramuscularly. P=pIRES IL-12; V=control plasmid, pND2Lux; E=electroporation.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings, which form a part hereof, and within which are shown by way of illustration specific embodiments by which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the invention.

Materials and Methods

Tumor cells and mice. B16.F10 murine melanoma cells (CRL 6475; American Type Culture Collection, Rockville, Md.) were maintained in Dulbecco's minimal Eagle's medium (DMEM) supplemented with 10% FCS and 0.2% gentamicin. Cells were trypsinized and washed in sterile PBS before injection. The left flank of C57BL/6 mice (National Cancer Institute, Bethesda, Md.) was shaved and 1×10^6 cells in 50 μ l of sterile PBS were injected subcutaneously. When challenged, mice were injected with 5×10^5 B16.F10 cells in the right flank. Tumors were measured using digital calipers, and treatment was begun when tumors reached 3-5 mm in diameter, ~7-10 days after injection. Tumor volume (v) was calculated using the formula $v = a^2 b \pi / 6$, where a=the smallest diameter and b=the perpendicular diameter. Mice were housed in accordance with AALAM guidelines.

Plasmid DNA. pIRES IL-12 was a gift from Karin Moelling (University of Zurich, Zurich, Switzerland). Briefly, pIRES IL-12 contains both subunits joined by an internal ribosomal entry site (IRES) behind a single cytomegalovirus (CMV) promoter. Robert Malone (Gene Delivery Alliance, Inc., Rockville, Md.) donated the pND2Lux, which encodes the reporter gene luciferase. Qiagen Mega Kits (Qiagen, Valencia, Calif.) were used for plasmid preparations. pIRES IL-12 was prepared with an endotoxin-free kit. All plasmid DNA was diluted in sterile injectable saline (0.9%) and stored at -20° C.

Intratumor treatment. Mice were anesthetized using 97% oxygen and 3% isoflurane. Tumors were injected with 50 μ l (1 μ g/ml) plasmid DNA in sterile saline using a tuberculin syringe with a 25-gauge needle. A applicator containing six penetrating electrodes ~1 cm in diameter was inserted into the tumor. Six pulses were delivered at 1500 V/cm (99 μ s, 1 Hz) using a BTX T820 pulse generator (BTX, San Diego, Calif.).

Intramuscular treatment. Mice were anesthetized as described earlier. The skin surrounding the gastrocnemius muscle was shaved. Plasmid DNA diluted in sterile saline (50 μ l, 1 μ g/ml) was injected into the gastrocnemius muscle using a tuberculin syringe and a 25-gauge needle. An applicator specially designed for the mouse gastrocnemius containing four penetrating electrodes in a rectangular pattern was inserted into the muscle surrounding the injection site. A total of 12 pulses were delivered segmentally at 100 V/cm (20 ms, 1 Hz) using a BTX T820 pulse generator.

ELISA. Mice were humanely killed using CO₂ asphyxiation, and then blood and tumors were collected on each day from four mice per treatment group. For detection of cytokines in the serum, blood was collected by cardiac puncture and stored at 4° C. overnight. Serum was extracted from blood samples by centrifugation (3 minutes at 5000 rpm) at 4° C., and stored at -20° C. until analyzed. To measure cytokine levels within the tumor tissue, the tumors were removed, frozen immediately on dry ice, weighed, and then stored at

-80° C. For analysis, the tumors were thawed, and 1 ml of a solution containing PBS and 10% protease inhibitor cocktail (P8340; Sigma, St. Louis, Mo.) was added. The tissues were kept on ice, homogenized using a PowerGen 700 (Fisher Scientific, Pittsburgh, Pa.), centrifuged for 3 minutes at 5000 rpm at 4° C., and then supernatants were assayed by ELISA. Both serum and tumor samples were analyzed using murine IFN- γ and IL-12 p70 ELISA kits (R&D Systems, Minneapolis, Minn.). Serum levels were calculated as pg of cytokine per ml of serum. Cytokine levels in the tumor were calculated as pg of cytokine per mg of tumor.

Histology. Mice were humanely killed by CO₂ asphyxiation. Tumors were excised and placed in 50-ml conical tubes containing 10 ml of 10% formalin. The tissue was stained with H&E after fixation, as follows: after fixation in 10% neutral buffered formalin for 6 hours, representative tissue samples were processed into paraffin blocks using a Miles VIP tissue processor (Miles Inc., Mishawaka, Ind.). Briefly, tissues were dehydrated in ascending grades of ethanol, cleared in xylene, and infiltrated in paraffin (Tissue Prep 2; Fisher Scientific). Following embedding, tissues were sectioned on a standard rotatory microtome and 4- μ m sections were retrieved from a waterbath and mounted on glass slides. Three sections per tumor were examined. Sections were heat-dried and stained with H&E (Richard-Allan Scientific, Kalamazoo, Mich.) using standard histologic techniques. Using a synthetic mounting medium, coverslips were then placed.

Immunohistochemistry. Immunohistochemical staining was conducted to examine the tumors for the presence of CD4+ lymphocytes, CD8+ lymphocytes, and blood vessels using the following antibodies: rat anti-mouse CD4, rat anti-mouse CD8a (Ly2), and rat anti-mouse CD31 (PECAM-1), respectively (PharMingen, Cambridge, Mass.). Mice were humanely killed by CO₂ asphyxiation. Tumors were excised with scissors and the skin removed, then immediately frozen in a mixture of dry ice and ethanol, and stored at (80°) C. Frozen sections of 5 μ m were obtained. For immunohistochemical analysis, rat antimouse CD4, rat anti-mouse CD8a (Ly2), or rat anti-mouse CD31 (PECAM-1) was applied to tissue sections at a dilution of 1:50 and incubated for 30 minutes, followed by detection with the Vector Elite Rat IgG-Peroxidase kit at 2 \times concentration (15 minutes each in biotinylated anti-rat IgG and ABC complex). Immunostaining was carried out on the Dako autostainer. Sections were analyzed at $\times 400$ magnification.

Treatment of nude mice. BALB/c athymic nude mice were obtained from the National Cancer Institute and used at 7 weeks of age. B16.F10 cells were prepared as described earlier. Mice were injected subcutaneously in the left flank with 1×10^6 B16.F10 cells in 50 ml of sterile PBS. Treatment was begun when the tumors reached 3-5 mm in diameter. Mice received intratumor therapy as described earlier.

Statistical methods. Statistical analysis was performed by ANOVA or two-tailed Student's t-test.

FIGS. 1-7 provide the results of a two treatment protocol in accordance with the present invention. According to this protocol, IL-12 was delivered by in vivo electroporation. C57BL/6 mice were treated with established subcutaneous B16.F10 melanoma by injecting 50 μ g (1 μ g/ml) of plasmid DNA encoding IL-12 (pIRES IL-12) in sterile saline into the tumor or the gastrocnemius muscle, followed by electroporation. An applicator containing six penetrating electrodes was used to deliver 1500-V/cm, 100- μ s pulses intratumorally. For intramuscular delivery, an applicator, specifically designed for the mouse gastrocnemius muscle and containing four penetrating electrodes, was used to administer 100-V/

cm, 20-ms pulses, a protocol shown to result in high systemic IL-12 and IFN- γ expression. A single treatment did not result in long-term animal survival. Therefore, the following experiments administered a second treatment 7 days (day 7) after the initial treatment (day 0). Tumor size was evaluated throughout the experiment, and the results are presented as the fold increase over day 0 tumor volume for each treatment group as shown in FIG. 1A. Treatment with pIRES IL-12 injected intratumor, followed by electroporation slowed tumor growth, with nearly half, 8 out of 17, of the mice showing complete regression of their tumors. Progressive tumor growth was observed in mice receiving intramuscular injections of plasmid encoding IL-12 followed by electroporation. Mice not receiving electrical pulses, (P+E-), showed continued tumor growth until all mice were killed or succumbed to the tumor burden. Neither the administration of electroporation alone (P-E+) nor intratumor (i.t.) delivery of a control vector (pND2Lux) with electroporation (V+E+) decreased tumor growth. These results provide evidence that neither electrical pulses alone nor plasmid DNA is responsible for tumor regression. None of the treatment groups except the P+E+i.t. group showed tumor regression, although P+E-i.t. did show slower tumor growth than P-E- through day 14 ($P<0.05$).

Evaluation of mice 100 days after the initial treatment showed that 47% of mice, 8 out of 17, receiving intratumor. delivery of IL-12 with electroporation were tumor-free as shown in FIG. 1B. These mice were considered cured. All mice receiving i.t. treatment with IL-12 and electroporation experienced prolonged survival compared with animals in other treatment groups. None of the mice in the control groups survived longer than 35 days. Specifically, if left untreated or treated with pulses alone, mice did not survive longer than 21 days.

We challenged seven of the animals that showed complete regression and remained disease-free for 50 days in the right flank with B16.F10 tumor cells. No additional treatments were administered. Of the seven challenged, five were resistant to tumor growth on the right flank, while tumors grew in 100% of naive mice. This result suggests the development of an immune memory response following treatment of the initial subcutaneous tumor established on the left flank.

As mentioned earlier, IL-12 induces several effects on the immune system. To evaluate the cytokine expression induced by either intramuscular or intratumor treatment, serum was analyzed and tumor levels of IL-12 and IFN- γ . Serum levels of both cytokines were highest after intramuscular injection followed by electroporation as illustrated by FIG. 2A. Serum IL-12 peaked at 320 pg/ml 10 days after treatment, whereas serum IFN- γ induced by IL-12 expression peaked at 177 pg/ml on day 14. Serum levels of both cytokines were significantly greater from mice treated intramuscularly with electroporation than other treatments on days 5, 10, and 14 ($P<0.05$). Serum levels of these cytokines in mice treated with intratumor injection followed by electroporation were not significantly greater than expression in mice that received no treatment ($P>0.05$).

Analysis of IL-12 and IFN- γ expression within the tumors revealed that intratumor treatment with electroporation resulted in the presence of these cytokines at the tumor site (FIG. 2B). Intratumoral IL-12 reached 3 pg/mg of tumor tissue on day 5 and remained at that level through day 10, whereas IFN- γ levels peaked at 8.16 pg/mg of tumor on day 5. Treatment with pIRES IL-12 injected intratumorally followed by electroporation produced significantly higher ($P<0.05$) IFN- γ levels than other treatment groups on days 5 and 10. Although tumor expression of IL-12 reached 3 pg/mg of

tumor with intratumor treatment, as opposed to 0.64 pg/mg of tumor with intramuscular treatment, these levels were not significantly greater ($P>0.05$) as a result of a wide spectrum of expression levels in these tumors after intratumor treatment (0.5-6.9 pg/mg of tumor tissue).

Treatment with intramuscular injection followed by electroporation did not result in significant ($P>0.05$) cytokine expression within the tumors as shown in FIG. 2B. Following intramuscular treatment the highest IFN- γ expression measured was 1 pg/mg of tumor on day 17. Therefore, treatment protocols that did not result in tumor regression also did not produce intratumoral IL-12 or IFN- γ expression. These results support previous reports on the critical need for cytokine expression within the tumor.

Resistance to challenge following successful tumor regression suggests the development of an immune memory response. The tumors were examined histologically 5 days after initial treatment to evaluate the influx of immune cells to the tumor. Tumor sections were stained with hematoxylin and eosin (H&E) to distinguish infiltrating immune cells from tumor cells. The H&E-stained sections showed infiltration of lymphocytes into the tumors of mice 5 days after receiving intratumor injection of pIRES IL-12 followed by electroporation as shown in FIG. 3C. In contrast, mice not treated or receiving intramuscular treatment with electroporation did not display a great influx of lymphocytes as illustrated in FIGS. 3A and 3B. Treatment protocols not including in vivo electroporation (P+E- either intratumor or intramuscular) also did not result in the influx of lymphocytes (data not shown).

By immunohistochemical phenotyping, it is demonstrated that the lymphocytes observed in tumors following intratumor treatment with IL-12 and electroporation were CD4+ and CD8+ T cells as illustrated in FIGS. 4C and 4D. In comparison, lymphocytes were observed in limited numbers in untreated tumors as shown in FIGS. 4A and 4B. Treatment of mice with intramuscular injection followed by electroporation also resulted in limited lymphocytic infiltrate, similar to that characterizing the untreated control group of FIGS. 4E and 4F. Additionally, mice receiving injection of plasmid encoding IL-12 (P+E- intratumor or intramuscular) or control plasmid with electroporation (V+E+ intratumor) did not show infiltrating lymphocytes (data not shown).

To further evaluate the need for T lymphocytes in tumor regression, athymic nude mice deficient in T cells were used as the mouse model in place of C57BL/6 mice. These mice were injected with B16.F10 tumor cells subcutaneously and began treatment when tumors reached 3-5 mm in diameter. Mice received intratumor treatments as explained earlier: intratumor injections of plasmid encoding IL-12 without electroporation, intratumor injection of a control plasmid followed by electroporation, or intratumor injections of plasmid encoding IL-12 followed by electroporation. Because of the lack of successful response in C57BL/6 mice following intramuscular injection, we administered only intratumor treatments. None of the treatments in the nude mouse model resulted in tumor regression as shown in FIG. 5A. In addition, no mice in any treatment group survived longer than 30 days. This observation further suggests the necessity of a T-cell response for successful regression of B16.F10 melanoma tumors.

Another potential role of IL-12 on tumor regression is its effect on angiogenesis. To assess the antiangiogenic role of IL-12 on B16.F10 tumors in C57BL/6 mice, representative sections of three tumors from each treatment group were stained with anti-CD31 antibodies, marking endothelial cells. Five different areas of highest vascularity were examined at a

magnification of $\times 400$ for each group as illustrated by FIG. 6. A representative section of the vessels in an untreated tumor on day 0 is shown in FIG. 6A. FIGS. 6B and 6C show the large number of vessels present within untreated tumors or tumors from mice receiving intramuscular injection followed by electroporation on day 5. In contrast, FIG. 6D shows the reduction of blood vessels after intratumor injection and electroporation on day 5. Tumors from mice receiving injection of plasmid encoding IL-12 without electroporation (P+E- intratumor or intramuscular) or control plasmid with electroporation (V+E+) did not show a reduction in vasculature (data not shown).

In addition, vessels in each of the three tumors excised from untreated mice were counted, mice receiving intramuscular IL-12 and electroporation, and mice receiving intratumor IL-12 and electroporation. In FIG. 7, Table 1 shows the number of blood vessels counted in the field of highest vascularity at a magnification of $\times 400$ for each of the three excised tumors. Only intratumor injection followed by electroporation (P+E+ intratumor) resulted in significant ($P < 0.05$) vessel reduction compared with untreated animals. Although an antiangiogenic effect was observed following intratumor treatment with electroporation, the lack of response in the nude mouse model suggests that T cells may be a critical factor for obtaining regression of B16.F10 melanoma. An antiangiogenic response may, however, contribute to stabilization of tumor size while an immune response is mounted.

This report has demonstrated that IL-12 delivered in the form of plasmid DNA with the aid of electroporation can result in successful regression of B16.F10 tumors. The animals remain disease-free and are resistant to challenge at a distant site. The results of the two treatment protocol demonstrate nearly a 47% survival rate following gene therapy treatment of established subcutaneous B16.F10 melanoma.

In summary, the present invention provide a treatment modality that can eradicate established B16.F10 melanoma tumors and result in resistance to renewed tumor growth following challenge. Utilizing the two treatment protocol, after i.t. delivery of plasmid DNA encoding IL-12 by in vivo electroporation, 47% of mice showed complete regression of their tumors and remained disease-free. These mice were challenged with B16.F10 tumor cells, and five of seven remained tumor-free for an additional 100 days, after which they were humanely killed. Also, it is demonstrated that i.t. injection of plasmid DNA encoding IL-12 and electroporation is more effective than i.m. delivery for promoting tumor regression and prolonging animal survival. The success of this treatment in this tumor model stems from the local expression of IL-12 and IFN- γ , infiltrating lymphocytes, and inhibition of angiogenesis within the treated tumor.

FIGS. 8-12 are illustrative of the three-treatment protocol in accordance with the present invention. Regarding the short-term prevention of subcutaneous tumors at a distant site, C57Bl/6 mice were shaved on both flanks. Mice were injected subcutaneously in the left flank with 1×10^6 B16.F10 cells in 50 μ l of sterile PBS. Once tumors were established, measuring 3-5 mm in diameter, treatment was begun. Two types of experiments were performed. The first series of experiments, on the day of the first treatment, 5×10^5 B16.F10 cells in 50 μ l of sterile PBS were injected in the right flank of mice. The second set of experiments, 5×10^5 B16.F10 cells in 50 μ l of sterile PBS were injected in the right flank of mice three days after the left flank injection. For both sets of experiments, mice received intratumor or a combination of intratumor and intramuscular therapy to the initial tumor on the left flank as described previously. Pulse protocols are further

described within the results section. Established tumors on the left flank were continuously measured as described earlier, and the right flanks of the mice were monitored for tumor development.

Regarding the analysis of lung colonization, B16.F10 cells were prepared as previously detailed for subcutaneous injection. Either 1×10^5 or 5×10^5 B16.F10 cells in 50 μ l of sterile PBS were injected into the tail vein using a 1 cc syringe with a 30-gauge needle. Mice received intra-muscular treatment on the day of inoculation and four days later as described earlier. Twenty-one days following inoculation, mice were euthanized and their chest cavities exposed. Lung colonies appeared as black tumor nodules on the lung surface and were counted.

As shown previously with the two-treatment protocol, a 47% disease-free survival rate for greater than 100 days in mice bearing established subcutaneous B16.F10 tumors treated twice with i.t. injection of plasmid encoding IL-12 and electroporation. Five out of seven disease free mice were resistant to challenge following an additional inoculation of tumor cells in the opposite flank. We previously noted a poor response to the first treatment was often observed in tumors that did not fully regress. By the second treatment seven days later, these tumors had shown extensive growth and could possibly have been too large for successful regression by the additional treatment. Increases in the disease free survival rate were obtained by two methods. First, instead of two treatments three treatments were delivered to these mice on days 0, 4, and 7. Second, an intra-muscular treatment was added. As discussed earlier, it has been shown that intramuscular delivery of IL-12 plasmid results in a systemic production of IL-12 and IFN- γ (41). These mice also received three treatments.

The administration of three-treatments, whether i.t. alone or in combination with i.m., resulted in complete tumor regression and an increased disease free survival rate over two treatments as illustrated by FIG. 8. Both three-treatment protocols (i.t. alone or i.t. and i.m.) resulted in an 80% disease free survival rate, statistically significant ($p < 0.05$) over the 60% disease free survival rate resulting from the two-treatment protocol (FIG. 1b). The slight increase in the disease free survival rate with the two-treatment protocol over our previous results with two treatments (60% vs. 47%) was not statistically significant. All three of the treatment protocols delivering IL-12 plasmid by electroporation resulted in complete regression of the tumors and maintenance of a disease free status through 100 days. When challenged with B16.F10 cells, all 12 (100%) of the disease free mice in the three treatment groups were resistant, and eight out of nine mice (88.9%) in the two-treatment group were resistant, suggesting the development of an immune memory response. These treatment protocols were further examined in multiple tumor and metastatic models.

The experiments described above demonstrated that the formation of new tumors (opposite flank) could be prevented in a high percentage of mice that had a complete response and long-term disease free survival. To further examine the potential of this therapeutic approach, it was important to evaluate the ability to block the formation of new tumors prior to the regression of the primary tumor. On the same day that mice received the first treatment for an established B16.F10 tumor on the left flank, a second injection of B16.F10 cells were administered to the right flank. Mice were then evaluated for regression of the first tumor as well as prevention of establishment of the second tumor.

Treatment protocols that involved i.t. or i.t./i.m. injections and electroporation resulted in regression of the primary

tumors as well as prevention of the establishment of the secondary tumor (FIG. 9a,b). Secondary tumors developed in 27% mice receiving two treatments and 33% mice receiving either of the three treatment protocols (FIG. 9a). Of the mice receiving an i.t. injection of control plasmid followed by electroporation, 77% of mice developed secondary tumors. In the no treatment group, 55% mice developed the secondary tumor and 58% mice grew the second tumor in the group receiving i.t. injection only (FIG. 9a). Because of the aggressiveness of this tumor model, several mice in the control treatment groups succumbed to their primary tumor before the secondary tumor could develop. Therefore, the percentage of mice developing the secondary tumor may have been higher in these groups had the mice survived for a longer period of time. Survival (FIG. 9b) was significantly improved ($p < 0.01$) in all three groups that received both IL-12 plasmid and electroporation compared to no treatment, plasmid injection alone and injection of control plasmid followed by electroporation. The mean survival for each group was as follows: no treatment=17.9+/-6.7 days; plasmid injection alone=30.1+/-28.9 days; control plasmid followed by electroporation=20.6+/-6.0 days; i.t. and i.m. plasmid injection and electroporation (3 treatments)=59.5+/-27.7 days; i.t. plasmid injection and electroporation (2 treatments)=65.2+/-24.0 days; i.t. plasmid injection and electroporation (3 treatments)=68.6+/-31.8 days. Seven out of 15 (47%) mice treated with i.t. plasmid injection and electroporation (3 treatments) were considered "cured" as they had no evidence of disease 100 days post treatment. In the i.t./i.m. three treatment and the i.t. two treatment group 4 out of 15 (26%) were "cured".

A second series of experiments was performed to examine if this approach could prevent formation of distant subcutaneous tumors when the tumor cells were injected prior to treatment. Three days after mice received an injection of B16 cells in the left flank (approximately four days before mice received treatment for the established B16.F10 tumor on the left flank) we administered a second injection of B16.F10 cells to the right flank. As in the previous experiment, mice were evaluated for regression of the first tumor as well as prevention of establishment of the second tumor (FIG. 10a, b). Secondary tumors developed in 50% of mice receiving two or three i.t. treatments and 25% of mice receiving three i.t. and i.m. treatments (FIG. 10a). In the control groups: 100% of mice receiving i.t. injection of IL-12 plasmid without electroporation, 87.5% of the no treatment group and 75% of the mice receiving an i.t. injection of control plasmid followed by electroporation developed secondary tumors (FIG. 10a). A significant increase ($p < 0.05$) in survival was seen only in mice receiving three i.t. or i.t./i.m. treatments (FIG. 10b) compared to the 3 control groups. Survival of mice in the i.t. two treatment group was not significantly different than any of the other groups. The mean survival for each group was as follows: no treatment=21.8+/-4.8 days; plasmid injection alone=26.0+/-8.8 days; control plasmid followed by electroporation=23.5+/-6.6 days; i.t. and i.m. plasmid injection and electroporation (3 treatments)=37.9+/-11.2 days; i.t. plasmid injection and electroporation (2 treatments)=38.1+/-24.5 days; and i.t. plasmid injection and electroporation (3 treatments)=47.8+/-26.1 days. Only two mice, one in the i.t./i.m. group and the other in the i.t. two treatment group were tumor free at 100 days and considered "cured".

B16.F10 melanoma cells will form tumor nodules in the lungs after i.v. injection. Treatment of this model requires a protocol that does not involve a primary or subcutaneous tumor. Therefore, the proposed therapy must induce a systemic immune response that can respond to the tumor burden

in the lungs. We showed previously that i.m. injection of IL-12 plasmid followed by electroporation results in high serum levels of IL-12 and IFN- γ . Furthermore, these serum levels could be sustained for a longer period by adding a second treatment four days after the initial treatment.

In this model, C57Bl/6 mice i.v. with 1×10^5 B16.F10 cells was injected and administered i.m. treatment with 50 μ g of plasmid encoding IL-12 and electroporation. Four days following the injection and initial treatment, we administered a second treatment. Mice were euthanized 21 days later and their lungs examined for tumor nodules. The table of FIG. 11 shows that 37.5% of mice receiving treatment with IL-12 and electroporation developed lung colonies. Of those three, two mice presented with only one nodule. In contrast, 87.5% of mice not treated developed lung colonies and 75% of mice receiving i.m. injection of plasmid encoding IL-12 without electroporation or mice receiving i.m. injection of a control plasmid with electroporation developed tumor nodules.

To evaluate the efficacy of this treatment on a heavier tumor inoculation, 5×10^5 B16.F10 cells were injected, i.v. then administered treatments as described above. Because the mice in control groups began dying before 21 days, the data is shown as survival (FIG. 11). 100% of mice in the group receiving i.m. injection of plasmid encoding IL-12 with electroporation survived throughout the experiment. Of the control groups, 62.5% in the no treatment group survived, 75% mice in the injection only group survived, and 50% mice in the group receiving control plasmid followed by electroporation survived. Thus, i.m. injection of plasmid coding for IL-12 followed by electroporation results in the establishment of fewer lung colonies and increases survival of mice with a heavy tumor inoculation.

In accordance with the present invention is demonstrated delivery of plasmid encoding IL-12 by electroporation results in successful treatment of subcutaneous tumors as well as lung metastases. We have also shown that this approach is not only effective in treating established tumors but is also effective in preventing the formation of new tumors. The results also suggest that this approach may be useful in treating multiple subcutaneous tumors. There was a reduction in the formation of distant second tumors when only the primary tumor was treated. This effect was seen when the tumor cell injection occurred on the same day of treatment or 4 days prior to treatment. Although administration of other electroporation protocols, using plasmid IL-12, have shown some regression or delay of tumor growth, the treatment protocols presented here have shown the highest rate of success against murine B16.F10 melanoma.

The lack of adverse side effects from the administration of the electrical pulses themselves is an enticing factor for its use. Phase I and II human clinical trials administering electrical pulses for the delivery of chemotherapeutic agents showed success against local tumors. General anesthesia was not required, and the patients did not report any serious adverse events. During the administration of the pulses, patients acknowledged feeling individual pulses but did not report any residual sensation. Thus, the use of electrical pulses is certainly applicable to human use.

Furthermore, for gene therapy studies, electroporation can effectively enhance the delivery of naked DNA. Plasmid DNA does not require cell division, nor has it elicited serious toxicities or immune responses compared to delivery of recombinant protein or the use of viral vectors. As mentioned previously, Lohr et al. compared delivery of IL-12 by electroporation to adenoviruses and found significantly less side effects in the mice following treatment protocols with electroporation. While the use of in vivo electroporation for deliv-

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ery of plasmid DNA is in a relatively early stage of development, there have been several pre-clinical studies that suggest this approach may be useful against several cancer types. The present invention provides a method for the administration of a plasmid encoding IL-12 with electroporation has a therapeutic effect on primary tumors as well as distant tumors and metastases.

It will be seen that the objects set forth above, and those made apparent from the foregoing description, are efficiently attained and since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matters contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween. Now that the invention has been described,

What is claimed is:

1. A method of treating cancer, the method comprising: injecting an established cancerous tumor with an effective dose of plasmid coding for IL-12; and administering electroporation therapy to the established cancerous tumor, the electroporation therapy comprising the administration of at least one pulse having a field strength of at least 700V/cm and a duration of less than 1 millisecond resulting in the regression of the established cancerous tumor and metastases and the inhibition of new cancerous tumor growth.
2. The method of claim 1, wherein the established cancerous tumor is melanoma.
3. The method of claim 1, wherein the at least one pulse delivered to the tumor is about 1500V/cm.
4. The method of claim 1, wherein the duration of the at least one pulse is about 100 microseconds.
5. A method of treating cancer in a subject, the method comprising: injecting an established cancerous tumor with an effective dose of plasmid coding for IL-12; administering electroporation to the established cancerous tumor using six 1500V/cm pulses, each pulse being 100 microseconds in duration resulting in the regression of the established cancerous tumor and metastases and the inhibition of new cancerous tumor growth; injecting an effective dose of plasmid coding for IL-12 into the muscle tissue of the subject; and administering electroporation to the subject intramuscularly using twelve 100V/cm pulses, each pulse being 20 milliseconds in duration.
6. The method of claim 5, wherein the established cancerous tumor is melanoma.
7. A method of treating cancer, the method comprising: administering a first treatment at time T1, wherein the first treatment comprises injecting an established cancerous tumor with a first effective dose of plasmid coding for IL-12 and administering a first electroporation therapy to the tumor at time T1, the first electroporation therapy comprising the administration of at least one pulse having a field strength of at least 700V/cm and a duration of less than 1 millisecond; and administering a second treatment at time T2, wherein time T2 is a time later than time T1, wherein the second treatment comprises injecting the established cancerous tumor with a second effective dose of plasmid coding for IL-12 and administering a second electroporation therapy to the tumor at time T2, the second electropora-

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tion therapy comprising the administration of at least one pulse having a field strength of at least 700V/cm and a duration of less than 1 millisecond resulting in the regression of the established cancerous tumor and metastases and the inhibition of new cancerous tumor growth.

8. The method of claim 7, wherein the established cancerous tumor is melanoma.

9. The method of claim 7, wherein the at least one pulse of the first electroporation therapy delivered to the established cancerous tumor and the at least one pulse of the second electroporation therapy delivered to the tumor are about 1500V/cm.

10. The method of claim 7, wherein the duration of the at least one pulse of the first electroporation therapy delivered to the established cancerous tumor and the at least one pulse of the second electroporation therapy delivered to the established cancerous tumor are about 100 microseconds.

11. The method of claim 7, wherein the duration between time T1 and T2 is seven days.

12. The method of claim 7, further comprising:

administering a third treatment at time T3, wherein time T3 is a time later than time T2, wherein the third treatment comprises injecting the established cancerous tumor with a third effective dose of plasmid coding for IL-12 and administering a third electroporation therapy to the tumor, the third electroporation therapy comprising the administration of at least one pulse having a field strength of at least 700V/cm and a duration of less than 1 millisecond.

13. The method of claim 7, wherein the duration between time T1 and T2 is four days.

14. The method of claim 12, wherein the duration between time T2 and T3 is three days.

15. A method of treating cancer, the method comprising: administering a first treatment on day zero, the first treatment comprising injecting an established cancerous tumor with a first effective dose of plasmid coding for IL-12 and administering a first electroporation therapy to the established cancerous tumor, the first electroporation therapy comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration; and

administering a second treatment on day seven, the second treatment comprising injecting the established cancerous tumor with a second effective dose of plasmid coding for IL-12 and administering a second electroporation therapy to the established cancerous tumor, the second electroporation therapy comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration resulting in the regression of the established cancerous tumor and metastases and the inhibition of new cancerous tumor growth.

16. A method of treating cancer in a subject, the method comprising:

administering a first treatment on day zero, the first treatment comprising injecting an established cancerous tumor with a first effective dose of plasmid coding for IL-12 and administering a first electroporation therapy to the established cancerous tumor, the first electroporation therapy comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration; and

administering a second treatment on day seven, the second treatment comprising injecting the established cancerous tumor with a second effective dose of plasmid coding for IL-12 and administering a second electroporation

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therapy to the established cancerous tumor, the second electroporation therapy comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration resulting in the regression of the established cancerous tumor and metastases and the inhibition of new cancerous tumor growth; 5

injecting an effective dose of plasmid coding for IL-12 into the muscle tissue of the subject; and

administering electroporation therapy to the subject intramuscularly using twelve pulses delivered at 100V/cm at 20 millisecond duration. 10

17. A method of treating cancer in a subject, the method comprising:

administering a first treatment on day zero, the first treatment comprising injecting an established cancerous tumor with a first effective dose of plasmid coding for IL-12 and administering a first electroporation therapy to the established cancerous tumor, the first electroporation therapy comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration; 15

administering a second treatment on day four, the second treatment comprising injecting the established cancer- 20

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ous tumor with a second effective dose of plasmid coding for IL-12 and administering a second electroporation therapy to the established cancerous tumor, the second electroporation therapy comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration; and

administering a third treatment on day seven, the third treatment comprising injecting the established cancerous tumor with a third effective dose of plasmid coding for IL-12 and administering a third electroporation therapy to the established cancerous tumor, the third electroporation therapy comprising the administration of six pulses delivered at 1500V/cm at 100 microseconds pulse duration resulting in the regression of the established cancerous tumor and metastases and the inhibition of new cancerous tumor growth.

18. The method of claim 17, further comprising:

injecting an effective dose of plasmid coding for IL-12 into the muscle tissue of the subject; and

administering electroporation therapy to the subject intramuscularly using twelve pulses delivered at 100V/cm at 20 millisecond duration.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 8,026,223 B1
APPLICATION NO. : 11/164626
DATED : September 27, 2011
INVENTOR(S) : Richard Heller and Melinda Lee Lucas

Page 1 of 1

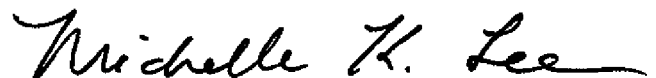
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 1, line 5, please insert

--This invention was made with government support under Grant Number R01 CA122518 awarded by National Institutes of Health. The government has certain rights in the invention.--

Signed and Sealed this
Twenty-seventh Day of October, 2015



Michelle K. Lee
Director of the United States Patent and Trademark Office