



(86) Date de dépôt PCT/PCT Filing Date: 1991/01/17
(87) Date publication PCT/PCT Publication Date: 1991/07/25
(45) Date de délivrance/Issue Date: 2006/11/21
(85) Entrée phase nationale/National Entry: 1992/09/10
(86) N° demande PCT/PCT Application No.: US 1991/000342
(87) N° publication PCT/PCT Publication No.: 1991/010680
(30) Priorité/Priority: 1990/01/17 (US466,577)

(51) Cl.Int./Int.Cl. *C07K 14/315* (2006.01),
A61K 35/14 (2006.01), *A61K 35/18* (2006.01),
A61K 38/19 (2006.01), *A61K 38/20* (2006.01),
A61K 38/21 (2006.01), *A61K 39/00* (2006.01),
A61K 39/02 (2006.01), *A61K 39/385* (2006.01),
A61K 39/39 (2006.01), *C07K 14/31* (2006.01),
A61K 38/00 (2006.01)

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(54) Titre : EFFETS TUMORICIDES D'ENTEROTOXINES ET DE COMPOSES CONNEXES
(54) Title: TUMOR KILLING EFFECTS OF ENTEROTOXINS AND RELATED COMPOUNDS

(57) **Abrégé/Abstract:**

Staphylococcal enterotoxins obtained by secretion from *Staphylococcus aureus*, by expression of enterotoxins in other bacteria or cells, or by chemical mutagenic treatment of *S. aureus* strains are used in treatment of cancer as tumorcidal agents. Enterotoxins (A, B, C, D, E and F) can be administered via simple intravenous injection at dosages between 0.5 µg/kg body weight to 150 µg/kg. Non-steroidal, anti-inflammatory agents and prostaglandin synthesis inhibitors such as ibuprofen may be simultaneously administered to attenuate toxic reactions from the enterotoxins. Streptococcus pyrogenic exotoxin and alpha hemolysin, which have structural and functional homology to the enterotoxins, are also useful in tumorcidal treatment. The enterotoxin gene transfected into tumor cells resulting in a tumor cell with surface expression of the minor lymphocyte stimulating locus with consequent potent activation and proliferation of T lymphocytes especially those with Vβ specificity, would also be useful in this application.



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International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁵ : C07K 7/10, 13/00	A1	(11) International Publication Number: WO 91/10680 (43) International Publication Date: 25 July 1991 (25.07.91) 2078003
(21) International Application Number: PCT/US91/00342 (22) International Filing Date: 17 January 1991 (17.01.91) (30) Priority data: 466,577 17 January 1990 (17.01.90) US (60) Parent Application or Grant (63) Related by Continuation US 466,577 (CIP) Filed on 17 January 1990 (17.01.90) (71)(72) Applicants and Inventors: TERMAN, David, S. [US/US]; 3183 Palermo Way, Pepple Beach, CA 93953 (US). STONE, Jay, L. [US/US]; 2695 Estates Drive, Aptos, CA 95003 (US).		(74) Agents: DERGOSITS, Michael, E. et al.; Limbach, Limbach & Sutton, 2001 Ferry Building, San Francisco, CA 94111 (US). (81) Designated States: AT (European patent), BE (European patent), BR, CA, CH (European patent), DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB (European patent), GR (European patent), IT (European patent), JP, KR, LU (European patent), NL (European patent), SE (European patent), US. Published <i>With international search report.</i> <i>With amended claims.</i>

(54) Title: TUMOR KILLING EFFECTS OF ENTEROTOXINS AND RELATED COMPOUNDS

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      10      20      30      40      50
STR-PRPSQLQSRNHLVKTFKIYIFFMRVTL-----VTNENVKSVQQLSHDLIYNVS--
: : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : :
ESQPDPKPDELHKSS--K-FTGLMENGKV-LYNNDHVSAINVKSINEFF--DLIYLYSIK
      10      20      30      40      50

      60      70      80      90
----GPNYDKLXTELXQEMATLFXDKQVVDIYGVEYYHLCYLC-----ENAERSAC
: : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : :
DTKLG-NYDNVRVETKXKDLADKYKDKYVDVFGANYIQ-CYFSKKTNNIDSHENTKXKTC
      60      70      80      90      100      110

      100      110      120      130      140      150
LYGGVTNHEGNHLEIPKK----IVVKVSIDGQISLSDIEQIKNGNCSRIS-YTVRKYLT
: : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : :
MYGGVTEHGNNQLD---KYYSITVRVFDGKNLLSFDVQTNKKKVTAEQLDYLTRHYLV
      120      130      140      150      160

      160      170      180      190      200
DNKQLYTNGPSKYETGYIKFIPKXKESFWDFPEPE--FTQSKYLMYKDNETLDSNTS
: : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : : :
XNKKLYEFNNSPYETGYIKFIE-NENSWYDMMPAPGNKFDQSKYLMYNNNDQVDSKDV
      170      180      190      200      210      220

      220
QIEVYLTTK
: : : : :
KIEVYLTTKKK
      230
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(57) Abstract

Staphylococcal enterotoxins obtained by secretion from *Staphylococcus aureus*, by expression of enterotoxins in other bacteria or cells, or by chemical mutagenic treatment of *S. aureus* strains are used in treatment of cancer as tumoricidal agents. Enterotoxins (A, B, C, D, E and F) can be administered via simple intravenous injection at dosages between 0.5 µg/kg body weight to 150 µg/kg. Non-steroidal, anti-inflammatory agents and prostaglandin synthesis inhibitors such as ibuprofen may be simultaneously administered to attenuate toxic reactions from the enterotoxins. Streptococcus pyrogenic exotoxin and alpha hemolysin, which have structural and functional homology to the enterotoxins, are also useful in tumoricidal treatment. The enterotoxin gene transfected into tumor cells resulting in a tumor cell with surface expression of the minor lymphocyte stimulating locus with consequent potent activation and proliferation of T lymphocytes especially those with V_β specificity, would also be useful in this application.

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**Tumor Killing Effects
Of Enterotoxins and Related Compounds**

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Technical Field

10 This invention relates generally to tumoricidal
compositions and methods, and more specifically to
the use of enterotoxins derived from, or homologous
to those derived from Staphylococcus aureus, to the
use of streptococcal pyrogenic exotoxins, TSST-1,
15 mycoplasma arthritidis, Mls antigens, homologous
synthetic polypeptides and derivatized enterotoxins.

Background Of The Invention

 Therapy of the neoplastic diseases has largely
involved the use of chemotherapeutic agents,
20 radiation and surgery. However, results with these
measures, while beneficial in some tumors, has had
only marginal or no effect in many others, while
demonstrating unacceptable toxicity. Hence, there
has been a quest for newer modalities to treat
25 neoplastic diseases.

 In 1980, tumoricidal effects were demonstrated
in four of five patients with advanced breast cancer
utilizing therapy with plasma perfused over
Staphylococcal Protein A. Terman, D.S., Young, J.B.,
30 Shearer, W.T., Ayus, C., Lehane, D., Mattioli, C.,
Espada, R., Howell, J.F., Yamamoto, T., Zaleski,
H.E., Miller, L., Frommer, P., Feldman, L., Henry,
J.F., Tillquist, R., Cook, G., Daskal, Y., New Eng.
J. Med., 305, 1195, 1981. This elaborate system

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involved the administration of patient plasma which was perfused over a solid surface to which Staphylococcal Protein A was chemically attached. Protein A was prepared by batch fermentation of Staphylococcus. It was isolated from the media and partially purified by affinity chromatography.

While the initial observations of tumor killing effects with the immobilized Protein A perfusion system have been confirmed, additional results have been inconsistent. The explanation of these inconsistencies appears to be as follows. First, commercial Protein A has been shown to be an impure preparation, as evident from polyacrylamide gel electrophoresis studies. Secondly, various methods of the immobilization of Protein A to solid supports have been used, sometimes resulting in loss of biological activity of the plasma perfusion system. Thirdly, the plasma used for perfusion over the immobilized Protein A has been stored and treated in different ways, sometimes resulting in inactivation of the system. Moreover, the antitumor element present in this extremely complex perfusion system has not been previously defined. The system contained an enormous number of biologically active materials, to include Staphylococcal Protein A itself, Staphylococcal proteases, nucleases, exotoxins, enterotoxins and leukocidin, as well as the solid support and coating materials. Additional products included several anaphylatoxins generated in plasma after contact with immobilized Protein A. Finally, it is speculated that the biological activity of the system was due to extraction by Protein A of immunosuppressive immune complexes capable of blocking the host's antitumor response.

The present invention demonstrates that isolated Staphylococcal enterotoxins identified initially as

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contaminants in commercial Protein A can reliably reproduce the tumoricidal reactions and toxicity observed with the whole perfusion system. As such, these materials appear to represent the most active tumoricidal components in the Protein A perfusion system matrix. These materials demonstrate tumoricidal activity in small doses and produce tumoricidal effects and toxicity identical to that observed in animals and man with the whole Protein A perfusion system. However, the tumoricidal effects may be produced by a simple intravenous injection. Therefore, it has been possible to completely eliminate the elaborate and complex Protein A perfusion system, with its enormous number of component parts, unpredictable performance and potential toxicity problems. This system may be replaced by the enterotoxins which may be administered via simple intravenous injection and have the distinct advantages of convenience, reliability and safety over the cumbersome, inefficient and often ineffective extracorporeal Protein A perfusion system. There is no prior report in the literature or elsewhere of antitumor effects ascribable to this group of proteins.

Enterotoxins have distinct advantages in inducing tumor killing effects over the more cumbersome and elaborate Staphylococcal Protein A plasma perfusion systems. One advantage is that enterotoxins are relatively simple proteins that may be infused after being solubilized in saline. This solubility obviates the need to immobilize Protein A or other biologicals on a solid support, and eliminates the requirement for perfusing plasma over a solid surface. Moreover, it bypasses problems associated with potential toxic reactions to impurities of Protein A. Consequently, enterotoxins

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appear to be far safer and more effective than previously described systems. Moreover, the system requires no elaborate sterilization and there is no problem with potential leaching of immobilized materials or chemical products from an inert surface as there would be with an extracorporeal column. Hence, this product offers decided advantages of effectiveness and convenience over the original system. Indeed, all evidence points to enterotoxins as being the most active antitumor product in the Staphylococcal Protein A plasma perfusion system.

Summary Of The Invention

The present invention provides enterotoxins derived from *Staphylococcus aureus* which are useful by themselves for the treatment of cancer. Enterotoxins are known to have molecular weights ranging from 22,000 to 38,000. They are heat stable, and resistant to trypsin digestion. According to one aspect of the present invention, enterotoxins isolated from media which is supporting the growth of various *Staphylococcus aureus* organisms are used in relatively pure form. When administered to subjects having tumors, the preparation induces a tumoricidal reaction: a hemorrhagic necrosis in tumor resulting in tumor regression. It should be understood that the term, "tumoricidal reaction," as used herein, means that the material under discussion promotes or assists in the killing of tumor cells.

Streptococcal pyrogenic exotoxin A, which has been shown to have statistically significant structural homology to enterotoxin B, is also useful for the treatment of cancer. The structural homology is supported by similar clinical responses: hypotension, fever, chills and septic shock. Additional biological properties common to these

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materials include mitogenic effects, interferon, interleukin and tumor necrosis factor induction activity.

Synthetic polypeptides with substantial structural homology and with statistically significant sequence homology and similarity to enterotoxin A, enterotoxin B and streptococcal pyrogenic exotoxins, including alignment of cysteine residues and similar hydropathy profiles, are also described as effective in tumoricidal therapy.

Thus, the present invention provides a pharmaceutical composition for treating tumors. The composition comprises:

(A) a tumoricidal effective amount of an agent, e.g., Staphylococcus aureus enterotoxin, and

(B) a pharmaceutically acceptable carrier.

In a preferred embodiment, the agent is selected from the group consisting of:

(i) a Staphylococcus aureus enterotoxin (SE);

(ii) a homologue of the SE that is capable of stimulating T cells via the T cell receptor $V\beta$ region and has a Z value of Lipman and Pearson algorithm in Monte Carlo analysis
5 exceeding 10,

(iii) a fragment of the SE or the homologue (ii), where the fragment has essentially the same biological activity as the SE(i) or the homologue (ii), and

(iv) a conjugate of the SE(i) with a monoclonal
10 antibody specific for a cell surface structure on a tumor target cell.

In another preferred embodiment, the agent is selected from the group consisting of:

(i) a staphylococcal pyrogenic exotoxin (SPE);

15 (ii) a homologue of the SPE(i); and

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5a

(iii) a fragment of the SPE(i) or the homologue(ii).

An aspect of the invention provides a commercial package comprising the above-mentioned pharmaceutical composition and a written matter which describes indications of the composition for use for treating tumors.

Brief Description of Figures

Figure 1 shows the alignment of amino acid sequences of staphylococcal enterotoxins and their relatives.

Figure 2 shows the alignment of amino acid sequences of mature streptococcal pyrogenic exotoxin A and staphylococcus aureus enterotoxin B.

Figure 3 shows the hypothetical structure for the complex of Class II MHC, T cell receptor, and staphylococcal enterotoxins or Mls.

15 Description of the Specific Embodiments

The enterotoxins of Staphylococcus aureus form a group of serologically distinct extracellular proteins, designated A, B, C₁, C₂, C₃, D, E and F. These proteins are recognized as the causative agents of Staphylococcal food poisoning. Enterotoxin F appears to be important in the pathogenesis of the Staphylococcal toxic shock syndrome. Ingestion of preformed enterotoxin in contaminated food leads to the rapid development (within two to six hours) of symptoms of vomiting and diarrhea that are characteristic of Staphylococcal food poisoning.

The enterotoxin proteins are of similar molecular weight. Characteristically, they have a

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disulfide loop near the middle of the molecule, and are easily soluble in water and salt solutions. They are relatively resistant to proteolytic enzymes and to heat. The higher level structural similarities between the enterotoxins is in agreement with the clinical picture where all of the enterotoxins seem to produce similar effects of sepsis, hypotension and fever. General properties of the enterotoxins are given in Table 1.

TABLE 1A
SOME PROPERTIES OF THE ENTEROTOXINS

	Enterotoxin			
	A ^a	B ^b	C ₁ ^c	C ₂ ^d
Emetic dose (ED ₅₀)(μg/monkey)	5	5	5	5-10
Nitrogen content (%)	16.5	16.1	16.2	16.0
Sedimentation coefficient (S _{20,w})(S)	3.04	2.78	3.00	2.90
Diffusion coefficient (D _{20,w})(x 10 ⁻⁷ cm ² sec ⁻¹)	7.94	8.22	8.10	8.10
Reduced viscosity (ml/gm)	4.07	3.81	3.4	3.7
Molecular weight	34,700	30,000	34,100	34,000
Partial specific volume	0.726	0.726	0.728	0.725
Isoelectric point	6.8	8.6	8.6	7.0
Maximum absorption (mμ)	277	277	277	277
Extinction (E _{1cm} ^{1%})	14.3	14.4	12.1	12.1

- ^a F.S., Thadhani, K., Schantz, E.J., Bergdoll, M.S., Biochemistry 5, 3281, 1966.
- ^b Bergdoll, M.S., Borja, C.R., Avena, R.M., J. Bacteriol. 90, 1481, 1965.
- ^c Borja, C.R., Bergdoll, M.S., Biochemistry 6, 1467, 1967.
- ^d Avena, R.M., Bergdoll, M.S., Biochemistry 6, 1474, 1967.

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TABLE 1B
Physicochemical Properties of Staphylococcal Enterotoxins*

Property	Enterotoxin					
	A ^a	B ^b	C ₁ ^c	C ₂ ^d	D ^e	E _f
Emetic dose for monkey (μg)	5	5	5	5-10	-	-
Sedimentation coefficient (S _{20,w})	3.03	2.89	3.0	2.9	-	2.6
Molecular weight	27,800	28,366 ^g	26,000	34,100	27,300	29,600
Isoelectric point	7.26	8.6	8.6	7.0	7.4	7.0
C-terminal residue	Serine	Lysine	Glycine	Glycine	Lysine	Threonine
N-terminal residue	Alanine	Glutamic acid	Glutamic acid	Glutamic acid	Serine	-

^a Schantz, E.J., Roessler, W.G., Woodburn, M.J., Lynch, J.M., Jacoby, H.M., Silverman, S.J., Gorman, S.J., Biochemistry 11, 360, 1972.

^b Schantz, E.J., Roessler, W.G., Wagman, J., Spero, L., Dunnery, D.A., Bergdoll, M.S., Biochemistry 4, 1011, 1965.

^c Borja, C.R., Bergdoll, M.S., Biochemistry 6, 1467 (1967).

^d Avena, R.M., Bergdoll, M.S. Biochemistry 6, 1474 (1967).

^e Chang, P.C., Bergdoll, M.S., Biochemistry, 18, 1937, 1979.

^f Borja, C.R., Fanning, E., Huang, I.Y., Bergdoll, M.S., J. Biol. Chem. 247, 2456, 1972.

^g Dayhoff, M. ed. (1972) Data Section. In Atlas Protein Sequence Structure 5 : D227 National Biomedical Research Foundation, Washington, D.C. (determined from the amino acid sequence of Huang and Bergdoll, 1970). Huang, I.Y., Bergdoll, M.S., J. Biol. Chem. 245, 3493, 1970.

* Modified from Bergdoll, M.S., Czop, J.K., Gould, S.S., Enterotoxin Synthesis by the Staphylococci. In: Recent Advances in Staphylococcal Research, pp. 307-316, Yotis; W.W. (Ed.) Ann. N.Y. Acad. Sci. Vol. 236.

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Amino acid compositions of enterotoxins A, B, C₁, C₂ and E reveal a high content of lysine, aspartic acid and tyrosine. Enterotoxins A and E are similar in methionine, leucine and arginine content, differing in this regard from enterotoxins B, C₁ and C₂. The amino acid sequence of enterotoxin B was found to consist of 239 amino acids. Half-cystine residues found at positions 92 and 112 form a disulfide bridge, and it has been suggested that the primary structure in this region may be common to all of the enterotoxins.

The protein sequences and immunological cross reactivity of the enterotoxins reveal that they can be divided into two related groups. SEA (Staphylococcal enterotoxin A), SEE and SED constitute one group, and SEB, SEC and Streptococcal pyrogenic exotoxin A (SPEA) make up the second group. Amino acid sequences show that SEA and SEE are almost identical and that SEB, SEC and SPEA share regions of similar sequence. SED is moderately related to both groups although it is more similar to the SEA group. There is a striking amino acid similarity among enterotoxins A, B, C, D and E in the region immediately downstream from cystine located at residue 106 in SEA. A second region at residue 147 also shows a highly conserved sequence. These regions are contained on the peptide fragment of SEC, shown to contain the active sites for emesis and diarrhea. The mitogenic region resides in the C terminal tryptic fragment of SEC, implying that other regions of sequence similarity exist. Amino acid sequence similarities and congruences are given in Tables 2-4.

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TABLE 2*

SEQUENCE SIMILARITIES AMONG THE
PYROGENIC TOXINS AND ENTEROTOXINS

TOXIN	SEQUENCE			
	106	119	147	163
SEA	CMYGGVTLHDNNRL		KKNVTVQELDLQARRYL	
SEB	CMYGGVTEHHGNOL		KKKVTAQELDYLTRHYL	
SEC1	CMYGGITKHEGNHF		KKSvTAQELDIKARNFL	
SED	CTYGGVTPHEGNKL		KKNVTVQELDAQARRYL	
SEE	CMYGGVTLHDNNRL		KKEVTVQELDLQARHYL	
SPEA	CIYGGVTNHEGNHL		KKMVTAQELDYKVRKYL	
Consensus	CMYGGVTLHEGNHL		KKNVTAQELD ^L _Y QAR ^R _H YL	
TSST-1	IHFQISGVTNTEKL		KKQLAISTLDFEIRHQL	

* Iandolo, J.J., Annu. Rev. Microbiol., 43, 375, 1989.

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TABLE 3

Amino Acid Composition of the Enterotoxins
(g 100g protein)

Amino Acid	Enterotoxin				
	A*	B†	C ₁ ‡	C ₂ ‡	ES
Lysine	11.26	14.85	14.43	13.99	10.83
Histidine	3.16	2.34	2.91	2.87	3.04
Arginine	4.02	2.69	1.71	1.75	4.50
Aspartic acid	15.53	18.13	17.85	18.38	15.10
Threonine	5.96	4.50	5.31	5.80	6.36
Serine	2.99	4.05	4.58	4.81	4.72
Glutamic acid	12.36	9.45	8.95	8.93	12.15
Proline	1.35	2.11	2.16	2.23	1.93
Glycine	2.96	1.78	2.99	2.90	4.10
Alanine	1.94	1.32	1.85	1.61	2.38
Half-cystine	0.66	0.68	0.79	0.74	0.81
Valine	4.93	5.66	6.50	5.87	4.36
Methionine	0.96	3.52	3.20	3.60	0.45
Isoleucine	4.11	3.53	4.09	4.02	4.30
Leucine	9.78	6.86	6.54	6.13	10.08
Tyrosine	10.63	11.50	9.80	10.27	9.79
Phenylalanine	4.31	6.23	5.35	5.25	4.47
Tryptophane	1.46	0.95	0.99	0.84	1.51
Amide NH ₃	1.80	1.66	1.71	1.62	1.66
TOTAL	98.37	100.15	100.00	99.99	100.88

* Schantz et al., 1972.

† Bergdoll, M.S., Chu, F.S., Huang, I.Y., Rowe, C., Shih, T., Arch Biochem Biophys, 112, 104, 1965.

‡ Huang, I.Y., Shih, T., Borja, C.R., Avena, R.M., Bergdoll, M.S., Biochemistry, 6, 1480, 1967.

§ Borja et al., 1972.

¶ From Bergdoll, M.S., Huang, I.Y., Schantz, E.J., J. Agric. Food Chem. 22, 9, 1974.

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TABLE 4[†]Amino Acid Compositions of TSST-1a and 1b^a

Amino acid	Amino acid composition		
	TSST-1a residues per mole ^b	TSST-1b residues per mole ^b	TSST-1 clone ^b
Aspartic acid	26	27	25
Threonine	21	20	19
Serine	20	20	21
Glutamic acid	20	20	17
Proline	10	8	10
Glycine	13	14	11
Alanine	4	5	3
Half-cystine	0	0	0
Valine	5	5	5
Methionine	0	0	2
Isoleucine	15	15	17
Leucine	14	16	15
Tyrosine	10	8	9
Phenylalanine	7	7	7
Histidine	5	5	5
Lysine	23	24	21
Tryptophan	ND ^d	ND ^d	3
Arginine	4	5	4
	197	199	194

[†] Blomster-Hautamaa, D.A., Schlievert, P.M., Methods in Enzymology, 165, 37, 1988.

^aIsolated from strain MN8, as compared to the inferred amino acid composition of the TSST-1 structural gene.

^bResidues per mole values are based on a molecular weight of 22,000.

^cResidues per mole inferred from the DNA sequence of the TSST-1 structural gene. Blomster-Hautamaa and colleagues.

^dND. Not determined.

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Comparison of the primary sequences of the staphylococcal enterotoxins and their relatives is shown in Figure 1. The complete primary amino acid sequences of the staphylococcal enterotoxins and related proteins are shown aligned, with the exception of the sequences of the exfoliating toxins, which are shown aligned, with the exception of the sequences of the exfoliating toxins, which are shown aligned with each other, but not with the remaining toxins. The exfoliating toxin sequences are shown here for completeness, and because these toxins have properties related to those of the others (see below). Toxins shown are as follows: SEA to SEE, Staphylococcus aureus enterotoxins A to E; SPE A and C, Streptococcus pyogenes toxins A and C; TSST1, Staphylococcus aureus toxic shock - associated toxin; ETA and ETB, Staphylococcus aureus exfoliating toxins A and B. Data are from (9-17). Residues that are identical or that have changed to an amino acid with similar properties among at least two of the following: SEA, SEE, and SED, are highlighted in pink. Residues that are identical or that have changed to an amino acid with similar properties among at least two of the following: SEB, SEC1, and SED and at least two of SEB, SEC1, and SEC2, are highlighted in yellow. Single letter abbreviations for the amino acid residues are: A, Ala; C, Cys; D, Asp; E, Glu; F, Phe; G, Gly; H, His; I, Ile; K, Lys; L, Leu; M, Met; N, Asn; P, Pro; Q, Gln; R, Arg; S, Ser; T, Thr; V, Val; W, Trp; and Y, Tyr.

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There is evidence that indicates varying degrees of immunological relatedness between certain enterotoxins. Bergdoll, M.S., Borja, C.R., Robbins, R., Weiss, K.F., Infect. Immun., 4, 593, 1971; Bergdoll, M.S., Enterotoxins. In: Staphylococci and Staphylococci Infections ed. C.S.F. Easmon, C. Adlam 1, pp. 559-598, 1983, Landon, Academic; Freer, J.H., Arbuthnott, J.P., Pharm. Ther., 19, 55, 1983. A considerable degree of cross reactivity exists for antisera raised against one enterotoxin and other enterotoxins. It has been considered that the enterotoxins may contain major cross reactive antigenic sites, while each individual enterotoxin possesses minor specific antigenic regions. Common precipitating antibodies were formed between SEA and SED. In addition, enterotoxins B and C can react immunologically with antisera against either toxin type. Immunologic cross reactivity between Streptococcal pyrogenic exotoxin A and Staphylococcal enterotoxins B and C₁ has been shown. These results suggest a conserved domain present in the three exotoxins. SEA, SEB, SEC, SED, TSST-1 and the pyrogenic exotoxins have also been shown to share considerable DNA and amino acid homology. The enterotoxins, the pyrogenic exotoxins and TSST-1 therefore appear to be evolutionarily related and all belong to a common generic group of proteins.

It should be noted that the two Streptococcal toxins SPEA and C are about as similar to each of the Staphylococcal groups as they are to each other. Exfoliative toxins are of similar size to SEB and SEA with similar modes of action. They share several points of sequence similarity to the Staphylococcal enterotoxins. Overall there are several stretches at which similarities are apparent throughout the total group comprised of Staphylococcal enterotoxins, Streptococcal pyrogenic exotoxins and Staphylococcal exfoliative toxins. The

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longest of these, located two-thirds of the way through the proteins, is similar to sequences found at the COOH-terminal end of the human and mouse invariant chain.

Invariant chain is a polypeptide associated with
5 nascent MHC class II molecules. Class II molecules bind peptides and present them to T cells during immune responses. Indeed, many toxins bind to class II molecules. The shared sequences may indicate some or all of the invariant chain and toxin binding sites on class II
10 molecules.

The known structural homology between the enterotoxins and Streptococcal pyrogenic exotoxin is further supported by the identity of clinical responses. It is known that this exotoxin induces hypotension, fever, chills and
15 septic shock in man. It is hypothesized that this compound activates cytokines, such as interleukin 1, interleukin 2, tumor necrosis factor and interferon, and procoagulant activity which are the prime mediators of the clinical symptomatology. It is hypothesized that many
20 other bacterial products are capable of inducing similar in vivo activity. Among potential tumoricidal agents which are likely candidates based upon structural homology or identity of clinical symptomatology are gram positive bacterial products, cell wall bacterial constituents such
25 as peptidoglycans and various gram negative bacterial components to include meningococcal, pseudomonous and E. Coli products. While presently undemonstrated in animal systems, it is believed that these agents are likely to possess similar tumoricidal utility as those claimed here
30 for the enterotoxins.

The recognition that the biologically active regions of the enterotoxins and SPEA were substantially structurally homologous enables one to predict synthetic polypeptide compounds which will exhibit similar tumoricidal effects.
35 Figure 2 illustrates the amino acid sequence homology of

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mature SPEA and Staphylococcus aureus enterotoxin B. The top sequence is the SPEA-derived amino acid sequence. The amino acid sequence of enterotoxin B is on the bottom.

Sequences are numbered from the amino acid terminus, with amino acids represented by standard one character designations. (See Tables 5 and 6 below.) Identities are indicated by : and gaps in the sequences introduced by the alignment algorithm are represented by dashed lines. See Johnson, L.P., L'Italien, J.J., and Schlievert, P.M., "Streptococcal pyrogenic exotoxin type A (scarlet fever toxins) is related to staphylococcus aureus enterotoxin B," Mol. Gen. Genet. (1986) 203: 354-356.

One common methodology for evaluating sequence homology, and more importantly statistically significant similarities, is to use a Monte Carlo analysis using an algorithm written by Lipman and Pearson to obtain a Z value. According to this analysis, a Z value greater than 6 indicates probable significance, and a Z value greater than 10 is considered to be statistically significant.

Pearson, W.R., Lipman, D.J., "Improved tools for biological sequence comparison," Proc Natl Acad Sci U S A, April 1988, 85 (8) pages 2444-8; Lipman, D.J., Pearson, W.R., "Rapid and sensitive protein similarity searches," Science, March 22, 1985, 227 (4693) pages 1435-41.

In the present invention, synthetic polypeptides useful in tumoricidal therapy are characterized by substantial structural homology to enterotoxin A, enterotoxin B and streptococcal pyrogenic exotoxins with statistically significant sequence homology and similarity (Z value of Lipman and Pearson algorithm in Monte Carlo analysis exceeding 6) to include alignment of cysteine residues and similar hydropathy profiles.

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TABLE 5

	<u>Amino Acid</u>	<u>One-letter Symbol</u>
5	Alanine	A
	Arginine	R
	Asparagine	N
	Aspartic acid	D
	Cysteine	C
10	Glutamine	Q
	Glutamic acid	E
	Glycine	G
	Histidine	H
	Isoleucine	I
15	Leucine	L
	Lysine	K
	Methionine	M
	Phenylalanine	F
	Proline	P
20	Serine	S
	Threonine	T
	Tryptophan	W
	Tyrosine	Y
	Valine	V
25		

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TABLE 6

	10	20	30	40	50
	STR-PKPSQLQRSNLVKTFKIYIPFMRVTL-----VTHENVKSVDQLLSHDLIYNVS--				
5	:	:	:	:	:
	ESQPDPKPDELHKSS--K-FTGLMENMKV-LYNNDHVSAINVKSINEFF--DLIYLYSIK				
	10	20	30	40	50
	60	70	80	90	
	-----GPNYDKLKTTELKNQEMATLFKDKNVDIYGVEYYHLCYLC-----ENAERSAC				
10	:	:	:	:	:
	DTKLG-NYDNVRVEFKNKDLADKYKDKYVDVFGANYIQ-CYFSKKTNNIDSHENTKRKTC				
	60	70	80	90	100
	100	110	120	130	140
	LYGGVTNHEGNHLEIPKK----IVVKVSIDGIQSLSFIDIEQIKNGNCSRIS-YTVRKYLT				
15	:	:	:	:	:
	MYGGVTEHGNNQLD---KYRSITVRVFEDGKNLLSFDVQTNKKKVTAEQLDYLTRHYLV				
	120	130	140	150	160
	160	170	180	190	200
	DNKQLYTNGPSKYETGYIKFIPKNKESFWDFPFPEPE--FTQSKYLMYKDNETLDSNTS				
20	:	:	:	:	:
	KNKKLYEFNNSPYETGYIKFIE-NENSFWDMMAPGNKFDQSKYLMYNNNDKMYVDSKDV				
	170	180	190	200	210
	220				
	QIEVYLTTK				
25	:	:	:	:	:
	KIEVYLTTKKK				
	230				

30 The enterotoxins are presumed to function by affecting emetic receptors in the abdominal viscera which stimulate the emetic and diarrheal response. These toxins also stimulate T lymphocyte mitogenicity, procoagulant, chemotactic activity, as well as cysteinyl leukotriene, lymphokine, serine
 35 protease and thromboglobulin production. Cytokines known to be induced by enterotoxins induce interferon, tumor necrosis factor, interleukins one and two. They suppress immune responses, augment natural killer cell cytotoxicity, enhance gram-
 40 negative endotoxic lethality and induce fever and

hypotension. These additional properties are shared with the pyrogenic exotoxins of both *Staphylococcus aureus* and *Streptococcus pyogenes* and TSST-1. Synthetic polypeptides would also be expected to demonstrate similar responses.

The Staphylococcal enterotoxins A, B, C, D, E, toxic shock toxin (TSST-1), a product of *Mycoplasma arthritidis* and Mls antigens provoke dramatic T cell responses. Staphylococcal enterotoxins are the most powerful T cell mitogens known eliciting strong polyclonal proliferation at concentrations 10^3 lower than such conventional T cell mitogens as phytohemagglutinin. SEA is the most potent T cell mitogen, stimulating DNA synthesis at concentrations of 10^{-13} to 10^{-16} M in the human system. All stimulate a large proportion of both murine and human CD4+ and CD8+ T cells. Activity of these mitogens is tightly restricted by the major histocompatibility complex (MHC) class II antigens. It is proposed that the staphylococcal enterotoxins, streptococcal pyrogenic exotoxins, exfoliative toxins and a product of *Mycoplasma arthritidis* bind directly to the T cell receptor and to class II MHC. These two structures are brought into contact, thus stimulating T cell activation via the V_β region of the T cell receptor mimicking strong alloreactive response.

Many toxins have binding affinities for MHC class II molecules which are involved in stimulating T cells. For example, SEA has a K_d for human class II of about 3.2×10^{-7} M, SEB of 10^{-6} M and TSST-1 of 10^{-7} M. SEA and SEB probably bind to the same site on class II because they cross compete for binding. Exfoliative toxins bind only weakly or not at all to class II. SEB and TSST-1 have different binding sites on class II molecules.

The structure of class II consists of two immunoglobulin-like domains located close to the cell membrane which supports a structure constructed from the NH₂ terminal regions of both polypeptides of the protein and comprise an extended β -pleated sheet supporting two alpha helices separated by a cleft. Peptides derived from foreign materials or from proteolysis of cell proteins normally lie in this groove. It is this complex of MHC and peptide that stimulates T cells bearing alpha and beta receptors. Bacterial toxins do not normally bind to MHC molecules by occupying this groove and therefore do not behave like conventional peptide-MHC binding antigens. Toxins bind to three different class II proteins, namely DR, DP, DQ (or murine I-A, I-E). SEB and TSST-1 bind to DR and DQ alleles but not to DP. Toxin-class II complexes stimulate T cells. Most toxins bind preferentially to DR class II proteins, less well to DQ and not at all to DP. Different DR alleles have different affinities for a few of the toxins most notably SEE. In the mouse, complexes of toxins plus I-E (murine DR equivalent) stimulate T cells more efficiently than complexes of toxins with I-A (murine DQ analog). There is also evidence for weak haplotype specificity, e.g., toxins bound to I-A^k stimulate T cells less well than toxins bound to I-A^d or I-A^b. Staphylococcus aureus toxins bind more efficiently to human class II proteins than to mouse. A likely location for toxin binding to MHC may be at the sides of class II where 2 wings, the ends of the β -pleated strands, extend to either side of the proteins.

A hypothetical structure for the complex of class II MHC T cell receptor and Staphylococcal enterotoxins and MHC protein is given in Figure 3.

5 The Figure shows a class II MHC protein, diagrammed according to Bjorkman and co-workers and Brown and co-workers, in contact with a T cell receptor and a staphylococcal enterotoxin or Mls product. Ag is the probable site of binding of a conventional antigenic peptide.

10 Toxins stimulate T cells through V_β binding. T cell receptors for antigenic peptides bound to MHC proteins are made up of 5 clonally variable components V_α , J_α , V_β , D_β , and J_β . Recognition of most conventional antigenic peptides bound to MHC proteins involve contributions from all the variable components of the T cell receptor.

15 In contrast, the toxins stimulate T cells almost exclusively via the V_β region of the T cell receptor. See Table 7 for binding of toxins to T cells bearing various V_β receptors.

TABLE 7

20	TOXIN	V_β SPECIFICITY	
		HUMAN	MOUSE
	SEA	?	1, 3, 10, 11, 17
25	SEE	5.1, 6.1-3, 8, 18	11, 15, 17
	SED	5, 12, ?	3, 7, 8.1-3, 11, 17
	SEB	3, 12, 14, 15, 17, 20	3, 7, 8.1-3, 17
	SEC1	12, ?	3, 8.2, 8.3, 11, 17
	SEC2	12, 13.1, 13.2, 14, 15, 17, 20	3, 8.2, 10, 17
30	SEC3	5, 12, ?	3, 7, 8.1, 8.2
	TSST1	2	3, 15, 17
	ExFT	2	3, 10, 11, 15, 17
	MAM	?	6, 8.1, 8.2, 8.3

35 This property of selective stimulation of V_β is reminiscent of the endogenous superantigens called Mls antigens in the mouse. The pattern of V_β

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specificity of the different toxins corresponds loosely with their groupings by sequence similarity. SEA, SED and SEE all stimulate murine T cells bearing $V_{\beta}11$ and SEE and SED both stimulate human T cells bearing $V_{\beta}5$. SEB and SECs stimulate mouse T cells bearing members of the $V_{\beta}8$ family and human T cells positive for $V_{\beta}12$. The exceptions are as follows: SED stimulates T cells bearing the $V_{\beta}8$ unlike SEA and SEE. Exfoliating toxin and TSST-1 which are not related by sequence have similar specificities for V_{β} both in mouse and humans.

Bacterial toxins and other superantigens do not bind to T cell receptors at those regions involved in binding to conventional antigenic peptides plus MHC. The superantigens engage V_{β} on an exposed face of V_{β} or a region predicted to be a β -pleated sheet and exposed on the side of the T cell receptor. This model predicts that toxins act as clamps engaging the sides of class II and V_{β} bringing into close proximity the surfaces of the T cell receptor and MHC that would contact each other during T cell recognition of conventional antigens bound in the groove of MHC. Proper confirmation must await x ray crystallographic resolution of the complex.

Neither class II nor toxins separately have affinities for the T cell receptors in question, but the combination of toxins and class II proteins do. Only if the complex peptide-MHC ligand has formed can it functionally engage the T cell receptor. The T cell activation via the $V_{\beta}B$ region of the T cell mimics strong alloreactive responses. This interaction occurs irrespective of whether the V_{β} is expressed on CD4+ or CD8+ T cells. This behavior is consistent with the known resistance of

Staphylococcal enterotoxins to proteolysis even in acidified conditions.

Mice Express Endogenous Equivalent of the Enterotoxins.

5 T cells from some mice responded well to spleen cells from some other animals even though both responder and stimulator were identical at the MHC. The antigens are called minor lymphocyte stimulating antigens (Mls). There are many Mls-like products
10 produced by mice controlled by non-linked loci. Mls products stimulate T cells bearing V_{β} S. Mls-1^a in combination with mouse class II molecules stimulate nearly all T cells bearing mouse V_{β} 6, 7, 8.1 and 9. A list of the Mls-like products and the V_{β} S they
15 engage is given in Table 8. Mls products have not yet been found in humans.

TABLE 8

Mls-like products identified in mouse.

LOCUS	V_{β} specificity	MHC association
Mls-1 ^a	6, 7, 8.1, 9	Class II (except q)
25 Mls-2 ^a	3	Class II (except q)
Mls-3 ^a	3	Class II (except q)
?	5	I-E
?	7	I-E
?	11	I-E
30 ?	17	I-E

A striking resemblance exists between T cell responses to Staphylococcal enterotoxins and T cell responses to the Mls locus. The Mls locus located on
35 chromosome 1 and other similar genes on other (unknown) chromosomes have profound effects on T cells. Polymorphism at these loci elicits a strong

primary mixed lymphocyte response between MHC identical and Mls disparate spleen cells in mice.

5 Mls products stimulate T cells bearing particular $V_{\beta}5$ almost regardless of the rest of the structure of the receptor on the T cell. This activity depends on the simultaneous expression by the presenting cell of class II proteins. Some class II products, most notably I-E molecules, present Mls products and bacterial toxins better than others.
10 Mls appear to engage $V_{\beta}S$ at the same site on the exposed face of the polypeptide as toxins.

The similarities between properties of bacterial toxins and mouse Mls products might lead one to suggest a structural similarity. Mls products
15 associate with class II and stimulate T cells via V_{β} much like superantigens but the structure of Mls is unknown.

There are consequences for mice expressing Mls products. They cause deletion in the thymus for all
20 prospective T cells bearing $V_{\beta}S$ with which they interact. Mice expressing Mls-1^a contain very few T cells bearing $V_{\beta} 6, 7, 8.2$ or 9 and hence are deprived of 20% of their total potential T cell repertoire. Despite this they do not seem to be
25 susceptible to disease.

Both Mls and enterotoxins show the following characteristics in common:

- 1 . Both activate a high frequency of normal
30 T cells exceeding that of conventional protein antigens.
2. Responding T cells are $CD4^{+}$.
3. T cells of many specificities respond.
4. Both elicit responses of T cells expressing
35 receptors having particular V_{β} gene products.

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5. There is no MHC restriction of responding T cells.
6. Both require presentation by class II MHC.
7. IE and IA molecules on antigen presenting cells are required for immunologic effects.
8. Ontogenetic deletion of V_{β} or $CD4^{+}8^{+}$ cells is induced by both molecules.

These similarities are summarized in Table 9.

TABLE 9

Similarities between the T cell responses to Mls and SE and differences with responses to protein Ag^a

Characteristic of the T Cell Response to:		Mls-1 ^a	SE	Proteins
15	High frequency of responding cells	Yes (~1:5)	Yes (~1:5)	No (~1:10 ⁴)
	Responding T cells $CD4^{+}$	Yes	Yes	Yes ^b
	T cell receptor involved in response	Yes	Yes	Yes
	T cells of many specificities respond	Yes	Yes	No
	V_{β} restriction of responding T cells	Yes	Yes	No ^c
20	MHC restriction of responding T cells	No	No	Yes
	Incompetent class II MHC alleles	Yes	Yes	Yes ^d
	I-E more involved than I-A	Yes	Yes	No
	Ontogenetic deletion of V_{β} on $CD4^{+}8^{+}$	Yes	Yes ^e	No
	Processing required	?	No	Yes
25	Pulsing APC stimulatory	?	Yes	Yes
	Pulsing T cell stimulatory	?	Yes	No
	Protein identified	No	Yes	Yes

^aData on T cell responses to Mls and SE derived from this paper and Janeway et al. A detailed description of the SE themselves is found in Bergdoll.

^bT cells expressing CD8 respond only to proteins degraded within cells; extrinsic proteins are presented by class II MHC to $CD4^{+}$ T cells.

^cT cell responses to protein antigens require all elements of the TCR, whereas those to Mls and SE appear to require only use of certain V_{β} segments.

^dPresentation of proteins is much more restricted in use of allelic forms of class II MHC molecules than is "presentation" of SE or Mls.

^eFrom Yagi and Janeway.

The striking functional similarity of Staphylococcal enterotoxins and Mls suggests that the Mls may represent a protein with homology to Staphylococcal enterotoxins. It has been proposed

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that the Mls like Staphylococcal enterotoxins directly binds the TCR-CD4 complex via its V_β domain and to class II MHC molecules assembling a complex that is highly stimulatory for T cells. Hence, both Mls and Staphylococcal enterotoxins are thought to ligate class II MHC to the TCR:CD4 complex in such a way as to stimulate a large percentage of T cells with restricted V_β usage.

While the animal studies described herein were carried out with Staphylococcal enterotoxins A and B, based upon the observed structural and reactive similarities, it would be expected that similar results would be obtained with the other Staphylococcal enterotoxins, SPEA, TSST-1, mycoplasma arthritidis, Mls antigens and the synthetic polypeptides described above. Additional biological properties common to this group include their mitogenic effects, interferon, interleukin and tumor necrosis factor induction activity. Furthermore, all are capable of inducing fever and shock when given intravenously to rabbits or monkeys, and most of these have been implicated as potential pathogenic agents in the toxic shock syndrome.

Production And Isolation Of Enterotoxins A, B, C, D, E and F

General Methods

Isolation and purification procedures for enterotoxins contain numerous common steps. On the whole, growth of enterotoxin producing Staphylococcus aureus strains is similar in all cases. The most widely used general medium for the culture of these organisms contains 3% MZ-amine Type A, or MAX, 3% protein hydrolysate powder, 0.00005% thiamine and 0.001% niacin. Optimum yields of the enterotoxins

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are obtained under controlled fermentation, where pH, temperature and oxygen tension are controlled. Typically, growth at 37°C for 18 to 24 hours is sufficient for maximum toxin yields. The yield of enterotoxin B and C₁ and C₂ will be up to several hundred μ grams (toxin)/ml (media), while the yield of other toxins will be only a few μ grams/ml.

All enterotoxins are secreted products.

Generally, they are produced during the logarithmic and stationary stages of cell growth. After growth, the producing cells are removed from the medium by centrifugation, and the toxin-containing supernatant is saved. If a large fermentation has been carried out, then the cells and supernatant can be quickly separated using a continuous flow centrifuge. To concentrate the toxins from the media, various methods, e.g., polyethylene glycol precipitation, or dialysis tubing precipitation, or hollow fiber concentration using membranes with selective molecular weight cutoffs can be used. To assess the purity of the isolated enterotoxin product, specific antisera to each of the toxins are used in appropriate quantitative immunoassays, e.g., radioimmunoassays or enzyme labelled immunoassays, hemagglutination, or precipitin reactions.

Enterotoxin Purification By Type

Enterotoxin B

The strain of *Staphylococcus aureus*, that is used for the production of SEB (Staphylococcal enterotoxin B) is e.g., S6 or 10-275. (Source: Dr. John Iandolo, Kansas State University, Manhattan, Kansas.) The medium containing the toxin is diluted twice with water adjusted to a pH of 6.4, and AmberLite^{*} CG-50 (200 mesh) cation ion-exchange resin is added to the

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toxin mixture. The toxin is eluted, dialyzed, then reappplied to the CG-50 column again. The eluted toxin is dialyzed, then applied to a column of carboxymethyl cellulose or CM-Sephadex*. Unbound proteins are eluted with 0.03 and 0.04 molar sodium phosphate buffer. At this point, the toxin is essentially homogeneous. Using chromatofocusing techniques, the SEB may be further subdivided into several isoelectric species using polybuffer 96.

10 Enterotoxin A (SEA)

High SEA producers, e.g., Staphylococcus aureus 13M-2909 (Source: Dr. John Iandolo, Kansas State University, Manhattan, Kansas) are grown in the general medium that is made 0.2% in glucose. Initially, AmberLite* CG-50 is used for batch isolation. After incubation, the toxin is eluted and dialyzed. The toxin is then loaded onto a CM-cellulose column and eluted with a linear gradient. The combined fractions are then loaded onto a hydroxylapatite column and eluted using a linear gradient. The fractions are lyophilized and chromatographed on a Sephadex*-G-75 column. The toxins obtained from this procedure are greater than 99% pure, with a yield of approximately 20%.

25 Enterotoxin C₁ (SEC₁)

Culture supernatant from Staphylococcus aureus 137 (Source: Dr. Marcia Betley, University of Wisconsin, Madison, Wisconsin) is concentrated, dialyzed and lyophilized. The toxin product is then applied to a carboxymethyl cellulose column and eluted with a stepwise gradient. The toxin peak consists of a sharp peak with a trailing edge. The eluted toxin is concentrated and applied to Sephadex*.

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G-75. The toxin elutes as a single peak. The toxin is then concentrated and run twice through a column of Sephadex^{*}-G-50. The eluate is dialyzed against water and lyophilized.

5 Enterotoxin C₂ (SEC₂)

 Culture supernatant from Staphylococcus aureus 361 (Source: Dr. Marcia Betley, University of Wisconsin, Madison, Wisconsin) is concentrated as for SEC₁ and dialyzed. The toxin is then applied to a
10 carboxymethyl cellulose column. SEC₂ is eluted, lyophilized and resuspended in distilled water. The toxin is reapplied to a column of carboxymethyl cellulose and eluted with a linear gradient. The partially purified toxin is concentrated and applied
15 to a Sephadex^{*}-G-75 column. The eluted toxin is concentrated and finally reapplied to a Sephadex^{*}-G-50 column. Recovery is about 40%, with purity exceeding 99%.

Enterotoxin D (SED)

20 Staphylococcus aureus 1151M (Source: Dr. John Iandolo, Kansas State University, Manhattan, Kansas) is used for the production of enterotoxin B. The medium is similar to that used for SEA and SEB. After growth and removal of the cells, the pH of the
25 supernatant is adjusted to 5.6 and applied to an AmberLite^{*}-CG-50 resin. The mixture is stirred for one hour, and the toxin is eluted and concentrated using 20% (W/V) polyethylene glycol, 20M. The concentrated toxin is dialyzed and applied to a
30 carboxymethyl cellulose column. The toxin is eluted in a linear gradient and then rechromatographed on carboxymethyl cellulose. The toxin solution is

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concentrated and chromatographed on Sephadex^{*}-G-75.
This step is repeated once.

Enterotoxin E (SEE)

5 Staphylococcus aureus strain FRI-236 (Source:
Dr. John Iandolo, Kansas State University, Manhattan,
Kansas) culture supernatant is concentrated and
dialyzed. The toxin is then absorbed to a
carboxymethyl cellulose column. The toxin is eluted
10 in a stepwise fashion and concentrated. It is then
chromatographed twice on Sephadex^{*}-G-75. To obtain
highly purified SEE, it is necessary to chromatograph
the toxin once more on G-75 in the presence of 6
molar urea.

15 Enterotoxin F or Toxic Shock Syndrome Toxin-1
(TSST-1), TSST-1a and TSST-1b

Staphylococcus strain MN8 (Source: Dr. Patrick
Schlievert, University of Minnesota, Minneapolis,
Minnesota) is cultured overnight in dialyzable beef
heart medium and precipitated from culture fluid by
20 adding 4 volumes of absolute ethanol and storing for
at least 2 days. The precipitate is collected by
centrifugation and the pellet is suspended in water,
recentrifuged and dialyzed to remove salts. The
preparation is then electrofocused in a pH gradient
25 of 3-10 using commercial ampholytes with the LKB
Multiphor^{*} apparatus. The visible band containing
TSST-1 is harvested and refocused in a pH 6-8
gradient yielding purified TSST-1.

30 TSST-1a and 1b are isolated by one additional
electrofocusing step. After focusing TSST-1 on the
pH 6-8 gradient, approximately one-half of the
Sephadex^{*} gel is removed from the anode end. The gel
remaining on the cathode end, containing the TSST-1

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band is repoured after the addition of two more grams of Sephadex^{*} gel and then refocused overnight using the remaining pH gradient. After electrofocusing in a pH 6-8 or 6.5-7.5 gradient, protein bands are located by the zymogen print method. Discrete bands are scraped off the plate and eluted with pyrogen free water from the Sephadex gel. Strain MN8 yields approximately 2 mg of each toxin per liter of culture fluid. For Staphylococcus aureus strains other than MN8, 200 µg of each toxin is obtained per liter of culture fluid. TSST-1a and 1b are proteins which migrate as homogeneous bands in SDS gels to a molecular weight of 22,000 with isoelectric points of 7.08 and 7.22, respectively.

With the changing technology of protein purification, new methods have been employed for the purification of certain enterotoxins from Staphylococcus aureus. Some of these methods are given here.

Enterotoxins A and C₂

A 10 ml culture of Staphylococcus aureus 11N-165 (SEA), Staphylococcus aureus 361 (Source: Dr. John Iandolo, Kansas State University, Manhattan, Kansas) (SEC₂) is grown overnight at 37°C. The removal of enterotoxin from the supernatant is carried out using QAE-Sephadex^{*}. The toxin is then eluted batchwise from the ion exchanger and recovered by filtration on a sintered glass funnel. The eluates are concentrated by ultrafiltration. The toxin is then passed through a Sephadex^{*}-G-100 column. Two peaks absorbing at 280 nm are eluted, with the latter containing the enterotoxin. The eluted toxin is concentrated and rerun on Sephadex^{*}-G-100. The overall recovery is about 30% for SEC₂ and 40 to 50%

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for SEA. Both toxins appear homogeneous by sodium dodecylsulfate polyacrylamide gel electrophoresis.

Enterotoxins A, C₁, D

5 This method utilizes fast protein liquid chromatography (FPLC) and high resolution chromatofocusing Mono P* column. Enterotoxins in media are concentrated and passed over a Sephadex*-G-75 column. The toxin containing fractions are pooled. For C₁ and D, the supernatants are passed
10 over an AmberLite*-CG-50 column, as described for SED, and the active fractions pooled. All three toxins are then placed in buffer for chromatofocusing and then separated using the MONO P* column FPLC system. Since all of the toxins have isoelectric points in
15 the range of 7 to 9, the polybuffer PBE-96 is used for elution. The purity of SEA, SEC₁ and SED is estimated to be 98, 95 and 80%, respectively. SEA elutes as two peaks at pH 8.8 and 8.6. SEC₁ also elutes as two peaks at pH 8.3 and 7.9, and SED elutes
20 as three peaks at pH 8.6, 8.3 and 8.0.

Enterotoxins may also be produced in mutant strains of Staphylococcus aureus by expression of an enterotoxin producing gene in another bacteria or cell. Genetic material which appears to be in the
25 chromosomal plasmid, or phage portion of the bacteria may be used for gene insertion procedures. Complete molecules or fragments with amino acid sequence homology to the parent enterotoxin may be produced with this technology. (Reviewed in Iandolo, J.J.,
30 Annu. Rev. Microbiol., 43, 375, 1989.) Moreover, mutagenic agents such as N-Nitroso compounds are capable of augmenting significantly the production of enterotoxins by some strains of Staphylococcus.

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Alpha Toxin

Staphylococcus aureus Wood 46 strain (Source: Dr. Sidney Harshman, Vanderbilt University, Nashville, Tennessee) is used and cultured in yeast extract dialysate medium. With the glass-pore bead method undialyzed yeast may be used together with casein, glucose, thiamin and nicotinic acid. The organism is incubated in medium for 24h at 37°C.

The culture supernatant is applied to a glass-pore bead column and adjusted to pH 6.8. A column of 5 x 20 cm is used for 3 liter batches and flow rates adjusted to 10-20 ml/min. The column is washed with 0.01M KHPO₄ pH 6.8 and then the alpha toxin is eluted with 1.0M KHPO₄ pH 7.5. Fractions are tested for the presence of alpha hemolysin by a rapid hemolytic assay using rabbit erythrocytes as substrate.

Streptococcal Pyrogenic Exotoxin (SPE)

(Erythrogenic toxin, scarlet fever toxin)

Streptococcus NY-5 strain (Source: ATCC 12351) has been the most widely used for toxin production and studies. A list of various strains to produce toxins A, B, and C has been published. The Kalbach S84 type 3 strain (Source: Dr. Joseph E. Alouf, Institute Pasteur-Unite Associee, Paris, France) is cultured and the supernatant is concentrated and stirred in calcium phosphate gel. Fraction S₁ is precipitated with 80% saturated ammonium sulfate. The redissolved pellet is dialyzed and termed Fraction S₂. This fraction is precipitated with 50-80% ammonium sulfate, resuspended in phosphate buffered saline (Fraction S₃), and gel filtered on a Bio-Gel^{*} P-100 column. The fraction corresponding to the volume eluted between 160 and 240 ml is collected and concentrated by ultrafiltration to about 20 ml in

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an Amicon^{*} PM10 Membrane (Fraction S₄). Fraction S₄ is then submitted to preparative isoelectric focusing (IEF) performed with a 100 ml column. The material which focuses at around pH 4.8 in a narrow peak is collected and dialyzed in an Amicon^{*} cell using PBS to eliminate ampholines and sucrose. The Fraction (S₅) constitutes purified pyrogenic exotoxin. Another electrophoretic form of SPE with a pI of 4.2 is often separated simultaneously with that of pI 4.8. Both forms show total cross reactivity against immune sera raised by rabbit immunization with fraction S₃.

The Fraction S₅ shows a single band by SDS-PAGE corresponding to a molecular weight of 28K. Bioassays for determination of activity include erythematosus skin test in rabbits or guinea pigs lymphocyte blast transformation. The toxin may also be detected by enzyme-linked immunoabsorbent assay (ELISA) or hemagglutination inhibition.

Experimental Animal Studies

1. Enterotoxins

Staphylococcus aureus strain FRI-722 was the production strain for SEA and strain I10-275 was the production strain for SEB. Both were grown in 3% enzyme hydrolyzed casein and 1% yeast extract at pH 6.6 at a temperature of 35-37°C for 16-20 hours. The culture medium is then filtered and incubated with AmberLite^{*} CG50 and the bound protein eluted with high ionic strength buffer (impure preparations). For further purification, this step is repeated and elution carried out with a low ionic strength to high ionic strength buffer gradient. The fraction containing SEB is concentrated, dialyzed and loaded onto a molecular sieve gel filtration column. The fraction containing SEB is concentrated and dialyzed

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against phosphate buffered saline pH 7.2, filter sterilized and frozen. Samples containing 5 and 10 mg/ml are tested in double diffusion immunoprecipitation assay using known standards of SEB and SEA with monospecific antisera. A single precipitation line was noted which showed a line of identity with known SEB and SEA, respectively. For enterotoxin B batches, polyacrylamide gel electrophoresis showed bands at 28,000 and a weaker band at 20,000 molecular weight. Purified enterotoxin A showed only a single band at 28,000 molecular weight.

High performance liquid chromatography (HPLC) profiles were obtained on a MAC PLUS* controlling a Rainin Rabbit* HPLC with a Hewlett Packard* 1040 A Diode array detector and a Vyadac* Protein and Peptide C18 column. The profile for purified enterotoxin B was a sharp peak without significant shoulder. There was minimal trace contamination. A functional hemolytic assay for the presence of alpha hemolysin in the pure preparation was negative. Purified enterotoxin batches were negative for endotoxin in the limulus amebocyte lysate assay. The sterility of the preparations was demonstrated by negative cultures in thioglycolate medium and soybean-casein digest. Protein determinations were carried out by a spectrophotometric method.

The functional activity of the toxins in vitro was tested using an established system of mitogenicity. Human peripheral blood lymphocytes 5×10^5 /well, were incubated in flat bottomed microtiter plates and stimulated with graded doses of exotoxins for various periods. Each well was pulsed with 1uCi [^{3} H] thymidine 18 hours before termination

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of the cultures which were harvested and processed for liquid scintillation counting.

2. Animals

New Zealand white female rabbits weighing from 2.5 to 5.0 kg, ages 2 to 4 months were used for studies employing purified enterotoxins. Rabbits of higher weight were used in the preliminary studies which are discussed in U.S. Patent No. 6,126,945.

The animals were obtained from the Elkhorn Rabbitry, Watsonville, California.

3. Tumor

The tumor used for these studies was obtained from the Frederick Cancer Research Facility of the National Cancer Institute. It was stored frozen in the DCT tumor repository. The tumor call lettered G50014 was also known as the VX-2. Stewart, H.L., Snell, K.C., Dunham, L.J. : Transplantable and transmissible tumors of animals. In Atlas of Tumor Pathology. Washington, D.C, Armed Forces Institute of Pathol., pp. 38, 355, 1959. The tumor is a carcinoma indigenous to the New Zealand white rabbit. It was stored as a tissue fragment, and suspended in saline. The tumor was initially induced by Shope virus and derived from a transformed papilloma in a dutch belted rabbit. Kidd and Rous described the tumor in 1937. Histopathologically, the tumor consists of cords and sheets of epithelial cells (80%) and 20% hemorrhage and necrosis with no acini. The growth is primarily papillary. Numerous mitoses are evident. The cells are thin walled and very anaplastic. The tumor used was cryopreserved from October 20, 1985. It had a negative viral profile.

4. Tumor inoculation

Tumor fragments for inoculation were obtained from VX-2 growing in rabbit thigh. Fragments were implanted intramuscularly into the right thigh of recipients. Donors were placed under general anesthesia with halothane (1.5%) and under sterile conditions, small fragments were excised and placed in Dulbecco's Modified Eagles Medium with glutamine (Gibco Life Technologies, Inc., Grand Island, NY 14072). The fragments were rinsed and then suspended in media until they were transferred into new hosts. Recipient rabbits had their right thigh shaved and scrubbed with alcohol and betadine. A small area was anesthetized with 1% lidocaine. With a scalpel, an incision was made through the skin into the muscle where a small pocket was created. With forceps, 4 to 5 tumor fragments were implanted into the muscle. The wound was closed with 1 or 2 nylon sutures. Tumors appeared at the implantation site within 4 weeks and therapy was started when the tumors were at least 1 to 2 centimeters in broad diameter.

5. Tumor measurements.

Tumors were measured by calipers by a certified veterinary oncologist before and at intervals after treatment. Complete remission was present when there was no evident tumor. Partial remission represented a reduction of tumor volume by greater than 50%. Less than partial remission was a 25-50% reduction in tumor volume.

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6. Conditions of Administration

Enterotoxins A and B in lyophilized form were diluted in 0.9% saline and then filtered through a 0.45 micron Millipore^{*} filter. Aliquots were stored at -20° F. An aliquot was thawed once, used only for a single injection and then discarded. Enterotoxin preparations in appropriate dose were prepared in 1 ml of 0.9% saline and drawn up in a 1 ml syringe. This solution was administered via the central ear vein which was cannulated with a 25 gauge needle and attached infusion tubing (Butterfly^{*}, 25 x 3/4 with 12" tubing set, Abbott Hospital, N. Chicago, IL 50064). The tubing and needle were initially washed with saline using a 3 ml syringe and with the tubing filled with saline, the toxin infusion was begun using a 1 ml tuberculin syringe (Monoject^{*} tuberculin 1.0 cc, Division of Sherwood Medical, St. Louis 63103). Approximately 0.3 ml of toxin was administered per minute. The tubing and needle were washed with 6 ml of normal saline over an additional 3 minutes using a 3 ml syringe. Partially purified enterotoxin B in doses of 100-150 µg enterotoxin/kg body weight or 40-60 µg enterotoxin/kg body weight were injected. Purified enterotoxin B was used in doses of 13-40 µg enterotoxin/kg body weight and purified enterotoxin A was used in doses of 0.5-12 µg enterotoxin/Kg body weight.

7. Enterotoxin Administration to Tumor Bearing Rabbits.

Preliminary studies in 20 rabbits using partially purified enterotoxin B as a single dose of 100-150 µg/kg or 40-60 µg/kg resulted in tumor regressions. With a dose of 40-60 µg/kg, six of twelve animals showed objective tumor regressions while a dose of 100-150 µg/kg resulted in objective tumor responses

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in three of nine rabbits treated. Results of these studies are given in U.S. Patent No. 6,126,945.

Toxicity

of these preparations was thought to be due to contaminating elements in particular staphylococcal alpha hemolysin. Accordingly, the next phase of these studies was carried out with purified enterotoxin B.

a) Purified Enterotoxin B

Purified enterotoxin B in a mean dose of 26 $\mu\text{g/kg}$ was administered to seven animals on one, two or three occasions (Table 10). Five showed complete remissions while one additional rabbit demonstrated 96% regression. One showed tumor progression. Of the four animals receiving a mean dose of 13 $\mu\text{g/kg}$, one had a complete remission while three showed tumor progression. A single animal given a dose of 40 $\mu\text{g/kg}$ died within 12 hours of injection. Six of eight animals with major regressions showed enduring responses lasting 2 to 6 months without evident tumor recurrence (Table 10).

b) Purified Enterotoxin A

SEA in a dose of 0.5 $\mu\text{g/kg}$ was given to 5 rabbits on two or three occasions. One showed a complete remission and a second 93.5% remission while two others demonstrated tumor progression and one died acutely after the third injection. SEA in a dose range of 5-12 $\mu\text{g/kg}$ was administered to 7 animals. Two achieved complete remission while one experienced a 60% remission. Four others died acutely after the first injection.

c) Purified TSST-1

One rabbit was treated with 0.5 $\mu\text{g/kg}$ of TSST-1 and showed a complete remission over 40 days.

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d) Untreated Control Animals

Five animals were inoculated with the VX-2 carcinoma as given above but were not treated with enterotoxins. All five showed progressive tumor growth over 90 days observation. No spontaneous remissions of tumor were observed.

TABLE 10

Purified Enterotoxin B (Lot TTB-16)

	<u>Animal Number</u>	<u>Maximum Response</u>	<u>Time to Maximum Response (days)</u>
	<u>Mean Dosage 26 µg/kg</u>		
	QT ²	complete remission	24
	Wanda ¹	complete remission	20
15	Cindy ²	complete remission	30
	Edna ²	complete remission	46
	Magnolia ³	complete remission	75
	Periwinkle ³	96%	68
	Heidi ²	progression	
20	<u>Mean Dosage 13 µg/kg</u>		
	KT ¹	complete remission	14
	Dinky ²	progression	
	Mazie ²	progression	
	Gretta ¹	progression	
25	<u>Mean Dosage 40 µg/kg</u>		
	Bonnie ¹	NC	12 hours (acute death)
30	1	One injection on day 0.	
	2	Two injections: One injection on day 0 and one injection on days 4, 5, 7 or 8.	
	3	Three injections: One injection on day 0, one injection on days 4 or 6, and one injection on days 11 or 13.	

35

8. Histology

Microscopically, tumors showed extensive hemorrhagic necrosis in samples obtained 12 to 72

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hours after the initial injection. Control untreated tumor showed focal areas of necrosis within the tumor, but no areas of hemorrhagic necrosis. Indeed, the areas of necrosis were far more extensive in the treated tumors with few if any areas of viable tumor. In the treated tumors, small blood vessels demonstrated hemostasis, and focal areas of inflammatory cell extravasation in the perivascular area. These changes were not seen in control untreated tumor specimens.

9. Toxicity

Acute toxic effects were observed in all animals after enterotoxin administration, to include temperature elevations of 2 to 5°F and anorexia. The animals became subdued. At the same time, the tumors became soft and mobile. There were signs of diarrhea in several animals. Toxicity of partially purified enterotoxin B is given in U.S. Patent No. 6,126,945.

a) Purified Enterotoxins A and B

With purified enterotoxin B, the dose range of 5-26 µg/kg was associated with fever and anorexia, while the 40 µg/kg dose was lethal in one animal tested. Five of seven rabbits given enterotoxin A in doses of 5-12 µg/kg died within 72 hours of the first dose. However, when the dose was reduced to 0.5 µg/kg four of five animals survived with two showing tumor regressions and one dying after the third injection. The surviving animals showed temperature elevations of 2° to 5° F and anorexia for 1-3 days after injection. During acute inflammatory activity in the tumor, animals often lost weight.

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10. Multiple injections of enterotoxins induce antitumor effects

5 Tumor bearing rabbits were given two or three injections of SEB, SEA or TSST-1 and showed tumor regressions. It is known that enterotoxins induce production of various cytokines and that one such cytokine namely interferon will in turn upregulate the surface expression of IA molecules and Class II major histocompatibility antigens. Such additional upregulated antigen presenting cells, would be further capable of binding additional enterotoxins and presenting them to the T lymphocyte repertoire. Moreover, a synergy has been noted between various cytokines namely tumor necrosis factor, interferon and various mitogens for T lymphocyte activation. Therefore, we may speculate that in the presence of various cytokines induced by the first injection of enterotoxins, upregulated antigen presenting cells are primed to bind additional toxin given in the second or third injection producing substantially augmented T cell proliferative responses and associated anti-tumor effects.

25 It is conceivable that the enterotoxins might be employed together with various cytokines such as IL-2 in vitro to develop a highly enriched population of T lymphocytes that could subsequently be injected at various intervals to continuously augment the anti-tumor effect in tumor bearing hosts.

30 Finally, while the enterotoxins were given intravenously in the present experiments, it is quite conceivable that the toxins could be administered in adjuvant form bound to vehicles such as aluminum hydroxide, liposomes, water in oil emulsions, pluronic triblock polymers and saponin with similar anti-tumor effects.

11. Attenuation of toxicity with Ibuprofen

The administration of Ibuprofen (20 mg/ml) given in doses of 0.25 to 0.5 ml subcutaneously when temperatures reached 105°F or greater resulted in reduction in fever by 2 to 5°F. Ibuprofen could be administered every 4 to 6 hours; however, in general, it did not need to be given more than once or twice per 24 hours. The use of this drug did not interfere with the observed tumor reduction or histologic hemorrhagic necrosis.

Ibuprofen may inhibit the prostaglandin mediated effects of the inflammatory cytokines including fever and anorexia but does not affect other antitumor immune and inflammatory responses.

Ibuprofen is only one of a large group of drugs known as non-steroidal anti-inflammatory agents (cyclooxygenase and prostaglandin synthesis inhibitors), which would also be useful to attenuate toxicity induced by the enterotoxins.

12. Genetic Aspects of Enterotoxin Production

Proceeding from the seminal work of Cohen & Boyer, U.S. Patent No. 4,237,224, DNA technology has become useful to provide novel DNA sequences and produce large amounts of heterologous proteins in transformed cell cultures. In general, the joining of DNA from different organisms relies on the excision of DNA sequences using restriction endonucleases. These enzymes are used to cut donor DNA at very specific locations, resulting in gene fragments which contain the DNA sequences of interest. These DNA fragments usually contain short single-stranded tails at each end, termed "sticky-ends". These sticky-ended fragments can then

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be ligated to complementary fragments in expression vehicles which have been prepared, e.g., by digestion with the same restriction endonucleases. Having created an expression vector which contains the structural gene of interest in proper orientation with the control elements, one can use this vector to transform host cells and express the desired gene product with the cellular machinery available. Once expressed, the gene product is generally recovered by lysing the cell culture, if the product is expressed intracellularly, or recovering the product from the medium if it is secreted by the host cell.

Recombinant DNA technology has been used to express entirely heterologous gene products, termed direct expression, or the gene product of interest can be expressed as a fusion protein containing some parts of the amino acid sequence of a homologous protein. This fusion protein is generally processed post-translationally to recover the native gene product. Many of the techniques useful in this technology can be found in Maniatis, T., et al., Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Laboratory, New York (1982).

However, while the general methods are easy to summarize, the construction of an expression vector containing a desired structural gene is a difficult process and the successful expression of the desired gene product in significant amounts while retaining its biological activity is not readily predictable. Frequently gene products are not biologically active when expressed in yeast, bacteria or mammalian cell systems. In these cases, post-translational processing is required to produce biological activity.

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From physical and genetic analysis, the genes for SEA, SEB, SEC, and SEE occupy a chromosomal loci. The structural gene encoding SED in all strains examined is localized, to a large penicillinase-like plasmid.

The enterotoxin A gene has been cloned. SEA was expressed in the E. coli genetic background from a single 2.5 kbp Hind III chromosomal DNA fragment. When sequenced, the DNA was found to contain a single reading frame that generated a protein consistent with the partial sequences of SEA derived by chemical methods. Therefore, it is apparent that the site mapped contained the structural gene for SEA.

Betley, M.J., Mekalanos, J.J., J. Bacteriol, 170, 34, 1987; Huang, I.Y., Hughes, J.L., Bergdoll, M.S., Schantz, E.J., J. Biol. Chem., 262, 7006, 1987; Betley, M., Lofdahl, S., Kreiswirth, B.N., Bergdoll, M.S., Novick, R.P. Proc. Natl. Acd., Sci., USA, 81, 5179, 1984.

The enterotoxin A gene was found to be at least 18 kilobases in length and was carried on a mobile element. Enterotoxin A production was linked to the presence of a bacteriophage which integrates into the bacterial chromosome. The enterotoxin A gene is located near the phage attachment. The enterotoxin A gene was mapped between the purine and isoleucine-valine markers in 24 Staphylococcus aureus strains. Conversion to the SEA producing phenotype was induced by lysogenization with a temperate phage purified from staphylococcal aureus strain PS42D. Therefore, a bacteriophage vector was found to be responsible for the toxin phenotype in suitable recipients.

The enterotoxin B gene has been cloned and expressed in E. Coli. The DNA of the gene derived from E. Coli has been sequenced and matches the

chemically derived sequence with only minor differences. Gaskill, M.E., Khan, S.A., J. Biol. Chem., 263, 6276, 1988; Jones, C.L., Khan, S.A., J. Bacteriol, 166, 29, 1986; Huang, I.Y., Bergdoll, M.S., J. Biol. Chem., 245, 3518, 1970.

The SEC gene has been cloned from the chromosome of *Staphylococcus aureus* MN Don. The cloned toxin was expressed in *E. coli* with a molecular weight comparable to that of the toxin from *Staphylococcus aureus*. The toxin was biologically active as measured by pyrogenicity, enhancement of lethal endotoxic shock and mitogenicity with murine splenocytes. The DNA sequence of the enterotoxin C gene has been developed and a protein sequence derived that compares favorably with the complete chemical sequence reported earlier. Bohach, G.A., Schlievert, P.M., Infect Immun., 55, 428, 1987; Bohach, G.A., Schlievert, P.M. Mol. Gen. Genet. 209, 15, 1987.

The enterotoxin D gene has been found to occur on a 27.6 kbp plasmid. The enterotoxin D gene has been cloned and expressed in *E. coli* and other *Staphylococcal* strains. The enterotoxin D gene in *Staphylococcus aureus* is under control of the agar locus like most *Staphylococcal* extracellular protein genes. The DNA sequence was determined encoding a mature protein with amino acid composition and reaction with antibody to SED confirming its identity to the biochemically purified toxin. Couch, J.L., Saltis, M.T., Betley, M.J., J. Bacteriol. 170, 2954, 1988.

The enterotoxin E gene has been cloned from *S. Aureus* FR1918 and was expressed in *E. coli* encoding an extracellular protein of 26,425 daltons. Its identity to SEE was confirmed immunologically and by

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correspondence of N terminal and C terminal analysis.
Kreishirth, B.N., Lofdahl, S., Betley, M.J.,
O'Reilly, Schlievert, P.M. Nature, 305, 709, 1983.

TSST-1 gene was not associated with either
5 bacteriophage or plasmid DNA. The gene was cloned on
a 10.6 kbp fragment of chromosomal DNA and
subsequently on an approximately 1 kbp subclone of
the larger fragment. The TSST-1 gene was expressed
in E. Coli, and TSST-1 was secreted into the
10 periplasm. The genetic element coding for TSST-1 was
found to occupy two loci on the Staphylococcus
genome. The loci are indicated by the notation Hi
555; one is at the junction of regions 1 and 2 and is
indistinguishable from att012 and closely linked to
15 tyrB. The second is within the trp operon at the
junction of regions 17 and 18. Hi555 encodes the tst
gene and is a heterologous insertion element that
provisionally exhibits some of the characteristics of
a transposon. Strains that are Trp⁻ contain Hi555 at
20 regions 17 and 18 (linked to Trp), while strains that
are Trp⁺ contain Hi555 elsewhere linked to TryB.
However, the Trp⁻ phenotype is not due to insertional
inactivation by the unusual element. The sequence
and analysis of the tst gene has been described. It
25 codes for a mature protein (TSST-1) of 197 amino
acids and a molecular weight of 22,049. Cooney, J.,
Mulvey, M., Arbuthnott, J.P., Foster, T.J., J. Gen.
Microbiol., 134, 2179, 1988.

Streptococcal pyrogenic exotoxin (SPEA) is
30 clearly related to the enterotoxins. It has a
cysteine loop of 9 amino acids similar to that of SEA
and is also encoded by a converting phage. SPEA
shows greater amino acid sequence similarity with SEB
than SEA. Immunologic studies show that the proteins
35 and antisera to either enterotoxin are cross

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reactive. Therefore, genes for all of the enterotoxins have been isolated and transfected into other bacteria to obtain selective production. These genes may be used as sources of accelerated
5 production of these toxins in high producing bacteria employing transfection techniques familiar to one skilled in the art. Iandolo, J.J., Annu. Rev. Microbiol., 43, 375, 1989.

High producing strains of Staphylococcus for
10 selective enterotoxin production have been identified and are available as described in enterotoxin purification section above. Moreover, exposure to mutagenic agents such as N-methyl-N'-nitro-N-nitrosoguanidine of enterotoxin producing
15 Staphylococcus aureus has resulted in a 20 fold increase in enterotoxin production over the amounts produced by the parent Staphylococcus aureus strain. Freedman, M.A., Howard, M.B., J. Bacteriol, 106, 289, 1971.

20 13. Transfections of Tumor Cells With Enterotoxin Genes

The genes for the enterotoxins and streptococcal pyrogenic exotoxins have been cloned. With their known mimicry of the Mls locus and their affinity for
25 T cell beta receptors, it would be logical to assume that transfection of the enterotoxin gene into tumor cells bearing appropriate HLA-DQ or DR or DP would result in production of a tumor cell bearing the minor lymphocyte stimulating locus capable of
30 ligating MHC class II molecules with T lymphocytes, therefore stimulating potent T cell proliferation and associated antitumor immunity.

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14. Bacterial Products Related to
Staphylococcal Enterotoxins With Similar
Biological Effects

5 Streptococcal pyrogenic exotoxin (SPE) is
produced by many strains of group A streptococci.
Three antigenically distinct types (A, B, C) have
been described. It is now known that Streptococcal
pyrogenic exotoxin or scarlet fever toxin is related
to Staphylococcus aureus enterotoxin B. The amino
10 acid sequence of SPE has significant homology with
Staphylococcus aureus enterotoxin B but not with
other proteins in the Dayhoff library. Figure 2
shows the alignment of amino acid sequences of mature
SPEA and Staphylococcus aureus enterotoxin B, as
15 reported in Johnson, L.P., L'Italien, J.J. and
Schievert, P.M. "Streptococcal pyrogenic exotoxin
type A (Scarlet fever toxin) is related to
Staphylococcus aureus enterotoxin B," Mol. Gen. Genet
(1986) 203:354-356.

20 The biological properties of SPE are shared with
some Staphylococcal enterotoxins such as lymphocyte
mitogenicity, fever induction and enhanced
susceptibility to endotoxin shock when given
intravenously. SPE activates murine T cells mainly
25 $V_{\beta}8.2$ in physical association with MHC class II
molecules expressed on accessory cells. SPE causes
deregulation of the immune response in vitro
resulting in delayed (12-16 days) acceleration of
humoral and cellular immune activity. This may
30 account for the sustained anti-tumor responses noted
with the use of its structural analog, namely
enterotoxin B, when administered to rabbits with the
VX2 carcinoma as demonstrated herein. Moreover, SPE
has now been shown to induce a toxic shock like
35 syndrome identical to that associated with various
enterotoxins. Given the biological and structural

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relatedness of these proteins, it would be anticipated that SPE and any other protein, bacterial or otherwise, with homology to enterotoxins would produce tumoricidal effects identical to those of enterotoxins.

15. Staphylococcal Enterotoxin Protein
Fragments With Biologic Activity

Studies of amino acid homology of Streptococcal pyrogenic exotoxin and enterotoxin B have suggested that there may be biologically active fragments present within the whole molecule. Indeed, cyanogen bromide generated toxin fragments of TSST-1 have been shown to be responsible for T lymphocyte mitogenicity and suppression of immunoglobulin synthesis. These functions could be selectively blocked by monoclonal antibodies directed to the respective fragments. Amino acid analysis of the toxins show that they contain similar domains that may give rise to mitogenic and emetic properties in susceptible cells. A peptide fragment in SEC was shown by Spero and Morlock to contain the active sites for emesis and diarrhea. The mitogenic region resided in the C terminal tryptic fragment of SEC.

An immune functional site on Staphylococcal enterotoxin A has been identified corresponding to residues 1-27 of SEA which is responsible for stimulation of T cell proliferation and induction of interferon- γ . This SEA (1-27) sequence corresponds to N-Ser-Giv-Lys-Ser-Glu-Glu-Ile-Asn-GFlu-Lys-Asp-Lev-Arg Lys-Lys-Ser-Glu-Leu-Gln-Gly-Thr-Ala-Lev-Gly-Asn-Lev-Ly and blocks SEA induced T cell proliferation and production of interferon γ which was not seen with SEA (28-48) peptide. Thus, a functional site on SEA responsible for modulation of

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T cell function involves the N-terminal 27 amino acids. These molecules may interact at either the level of TCR or the binding of SEA to class II MHC antigens.

5 For TSST-1, mitogenic activity was shown to be located on a 14,000 dalton cyanogen bromide generated toxin fragment. Other studies using proteolytic digestion of the TSST-1 with papain demonstrated mitogenic activity in 12,000 dalton fragment
10 occupying 2/3 of TSST-1 molecule toward COOH terminal end of holotoxin. On the other hand, non-specific mitogenicity of rabbit lymphocytes demonstrated by enterotoxins A, B, and C₁ was associated with the NH₂ terminal ends of the molecules.

15 The emetic reaction and a related immediate-type skin reaction to SEB appears to be mediated by histamine and cysteinyl leukotrienes liberated from mast cells. Enterotoxins probably act on
20 intramucosal or intradermal ganglion cells and the effect on mast cells is indirectly mediated by neuropeptides. Carboxymethylation of histidine residues of SEB caused a complete loss of emetic and skin sensitizing activity without changing the
25 immunological specificity, e.g., T cell stimulating activity. An anti-idiotypic monoclonal antibody against the combining site of an anti-SEB monoclonal antibody had no enterotoxic activity but can inhibit the enterotoxic activity, e.g., emetic response and diarrhea of a 10,000 molar excess of SEB. Anti-
30 idiotypic antibody also inhibited immediate-type skin reactions as well. The anti-idiotypic antibody and carboxymethylated enterotoxins may be useful tools to protect against the enterotoxin induced intestinal toxicity.

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Therefore, it could be predicted that fragments of the whole enterotoxin molecule can produce biologically active effects and predictably reproduce the in vivo tumoricidal activity of the whole molecule while eliminating some of the toxic effects noted.

Moreover, it would be reasonable to assume that similar or increased tumoricidal effects could be accomplished with biologically active fragments or intact enterotoxins alone or attached to antigen presenting cells (class II MHC, HLA-DR) and incubated ex vivo with a random T cell population or one which may have been pre-enriched for the appropriate V_β receptor. The activated T cell population with bound enterotoxin might then be reinfused into the host. Similar tumoricidal effects would be anticipated with enterotoxins or biologically active fragments infused into a host who has had an "organoid" (an enriched T lymphocyte organ) implanted on a biocompatible matrix and placed in a site in the host such as the abdominal cavity, adjacent to the liver or subcutaneously.

Although the foregoing invention has been described in detail for purposes of clarity of understanding, certain modifications may be practiced within the scope of the appended claims. While the above findings apply to an experimental animal model, it should be recognized that the tumor used herein is an excellent model of human cancer. Therapeutic success in the canine model with PACC system (described in U.S. Patent No. 5,091,091),

the forerunner of the present invention, was transferred to humans in which objective tumor regressions were obtained in four of the first five

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consecutive patients treated. Thus, the data given herein for rabbits with carcinoma is expected to be predictive of success when the compositions are applied to humans with spontaneous tumors as well.

5 In practice, the agents (i.e., the enterotoxins, their analogues, their fragments or monoclonal antibody-conjugates) may be formulated into pharmaceutical compositions together with pharmaceutically acceptable carriers and optionally other additives that are commonly employed in
10 pharmaceutical compositions. These carriers and additives are well known in the art and do not have to be described in detail. A preferred form of the composition is one adapted for injection or intravenous innoculation.

 The dose of the agent may vary widely depending on a
15 variety of factors. A preferred dose is from 0.5 to 150 µg per kg body weight per day.

 Those pharmaceutical compositions may be put in commercial packages for practical use, transportation, storage or the like. Such commercial packages usually carry written
20 matters which describe indications of the pharmaceutical compositions.

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CLAIMS:

1. A pharmaceutical composition for treating tumors,
which comprises:

(A) a tumoricidal effective amount of an agent which
5 is selected from the group consisting of:

(i) a Staphylococcus aureus enterotoxin (SE);

(ii) a homologue of the SE(i) that is capable of
stimulating T cells via the T cell receptor V β region and has a
Z value of Lipman and Pearson algorithm in Monte Carlo analysis
10 exceeding 10, and

(iii) a fragment of the SE(i) or the homologue (ii),
where the fragment has essentially the same biological activity
as the SE(i) or the homologue (ii), and

(B) a pharmaceutically acceptable carrier.

15 2. The pharmaceutical composition according to claim 1,
wherein the agent (A) is the SE(i).

3. The pharmaceutical composition according to claim 2,
wherein the SE(i) is selected from the group consisting of SEA,
SEB, SEC1, SEC2, SEC3, SED, SEE and SEF.

20 4. The pharmaceutical composition according to claim 2,
wherein the SE(i) is SEA or SEB.

5. The pharmaceutical composition according to claim 1,
wherein the agent (A) is a fragment of the SE(i) or the
homologue (ii) having essentially the same biological activity
25 as the SE(i) or the homologue (ii).

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6. The pharmaceutical composition according to claim 5, wherein the SE(i) is selected from the group consisting of SEA, SEB, SEC1, SEC2, SEC3, SED, SEE and SEF.

7. The pharmaceutical composition according to claim 1,
5 wherein the agent has a sequence as set out below:

CMYGGVTLHDNNRL,

CMYGGVTEHHGNOL,

CMYGGITKHEGNHF,

CTYGGVTPHEGNKL,

10 CMYGGVTLHDNNRL,

CMYGGVTLHEGNHL, or

IHFQISGVTNTEKL.

8. The pharmaceutical composition according to claim 1, wherein the agent has a sequence as set out below:

15 KKNVTVQELDLQARRAYL,

KKKVTAQELDYLTRHYL,

KKSVTAQELDIKARNFL,

KKNVTVQELDAQARRAYL,

KKEVTVQELDLQARHYL,

20 KKNVTAQELD (L or Y) QAR (R or H)YL, or

KKQLAISTLDFEIRHQL.

9. The pharmaceutical composition according to claim 5, wherein the fragment is:

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(a) that of SEA having an amino acid sequence containing at least CMYGGVTLHDNNRL or KKNVTVQELDLQARRAYL or both,

(b) that of SEB having an amino acid sequence
5 containing at least CMYGGVTEHHGNOL or KKKVTAQELDYLTRHYL or both,

(c) that of SEC1 having an amino acid sequence containing at least CMYGGITKHEGNHF or KKSMTAQELDIKARNFL or both,

10 (d) that of SED having an amino acid sequence containing at least CTYGGVTPHEGNKL or KKNVTVQELDAQARRAYL or both,

(e) that of SEE having an amino acid sequence containing at least CMYGGVTLHDNNRL or KKEVTVQELDLQARHYL or
15 both, or

(f) that of TSST-1 having an amino acid sequence containing at least IHFQISGVTNTEKL or KKQLAISTLDFEIRHQL or both.

10. The pharmaceutical composition according to claim 1,
20 wherein the agent (A) is the homologue (ii).

11. The pharmaceutical composition according to claim 10, wherein the homologue (ii) is a member selected from the group consisting of:

Staphylococcus aureus toxic shock-associated toxin
25 (TSST-1),

Staphylococcus aureus toxic shock-associated toxin a (TSST-1a), and

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Staphylococcus aureus toxic shock-associated toxin b
(TSST-1b) .

12. The pharmaceutical composition according to any one
of claims 1 to 11, which further comprises at least one
5 adjuvant selected from the group consisting of aluminum
hydroxide, liposome, water-in-oil emulsion, Pluronic* triblock
polymer and saponin.
13. The pharmaceutical composition according to any one
of claims 1 to 12, which further comprises a toxicity
10 attenuating dosage of a non-steroidal anti-inflammatory agent.
14. The pharmaceutical composition according to claim 13,
wherein the non-steroidal anti-inflammatory agent is ibuprofen.
15. The pharmaceutical composition according to any one
of claims 1 to 14, which is in a form adapted for intravenous
15 inoculation.
16. The pharmaceutical composition according to any one
of claims 1 to 14, which is in a form adapted for injection.
17. A commercial package comprising the pharmaceutical
composition as defined in any one of claims 1 to 15 and a
20 written matter which describes indications of the
pharmaceutical composition for use in treating tumors.
18. A commercial package comprising the pharmaceutical
composition as defined in claim 16 and a written matter which
describes indications of the pharmaceutical composition for use
25 in treating tumors.

*Trade-mark

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19. The commercial package according to claim 18, wherein the written matter describes that the injection is a single injection.

20. The commercial package according to claim 18, wherein
5 the written matter describes that the injection is multiple injections.

21. The commercial package according to any one of claims 17 to 20, wherein the written matter describes indications of the pharmaceutical composition for use in
10 treating carcinoma.

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FIG. 1A

	10	20	30	40
SEA	S	E	K	S
SEE	E	E	E	E
SED	S	E	E	E
SEB	E	S	Q	P
SEC1	E	S	Q	P
SEC3	S	Q	P	P
SPE A	Q	Q	D	P
SPE C	D	S	K	K
TSST-1				
ETA	E	V	S	A
ETB	K	E	Y	S
SEA	K	E	S	H
SEE	K	E	S	D
SED	K	S	T	G
SEB	K	-	S	I
SEC1	K	-	S	V
SEC3	M	-	S	V
SPE A	K	-	S	V
SPE C	F	S	T	H
TSST-1	F	-	S	N
ETA	D	R	Q	K
ETB	A	R	S	-

	50	60	70	80
SEA	K	E	S	H
SEE	K	E	S	D
SED	K	S	T	G
SEB	K	-	S	I
SEC1	K	-	S	V
SEC3	M	-	S	V
SPE A	K	-	S	V
SPE C	F	S	T	H
TSST-1	F	-	S	N
ETA	D	R	Q	K
ETB	A	R	S	-

	10	20	30	40
SEA	S	E	K	S
SEE	E	E	E	E
SED	S	E	E	E
SEB	E	S	Q	P
SEC1	E	S	Q	P
SEC3	S	Q	P	P
SPE A	Q	Q	D	P
SPE C	D	S	K	K
TSST-1				
ETA	E	V	S	A
ETB	K	E	Y	S
SEA	K	E	S	H
SEE	K	E	S	D
SED	K	S	T	G
SEB	K	-	S	I
SEC1	K	-	S	V
SEC3	M	-	S	V
SPE A	K	-	S	V
SPE C	F	S	T	H
TSST-1	F	-	S	N
ETA	D	R	Q	K
ETB	A	R	S	-

	50	60	70	80
SEA	K	E	S	H
SEE	K	E	S	D
SED	K	S	T	G
SEB	K	-	S	I
SEC1	K	-	S	V
SEC3	M	-	S	V
SPE A	K	-	S	V
SPE C	F	S	T	H
TSST-1	F	-	S	N
ETA	D	R	Q	K
ETB	A	R	S	-

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FIG. 1

[illegible]

FIG-1C

	170	180	190	200
SEA	K K N V T V Q E L D P Q A R R Y L Q E K Y N L Y N S D V F D G K V Q R G L I V F			
SEE	K K E V T V Q E L D L Q A R H Y L H G K F G L Y N S D S F G G K V Q R G L I V F			
SED	K K N V T V Q E L D A Q A R R Y L Q K D L K L Y N N D T L G G K I Q R G K I E F F			
SEB	K K K V T A Q E L D Y L T R H Y L V K N K K L Y - - E F N S P Y E T G Y I K F F			
SEC1	K K S V T A Q E L D I K A R N F L I N K K N L Y - - E F N S S P Y E T G Y I K F F			
SEC3	K K S V T A Q E L D I K A R N F L I N K K N L Y - - E F N S S P Y E T G Y I K F F			
SPE A	K K M V T A Q E L D Y K V R K Y L T D N K Q L Y - - T N G P S K Y E T G Y I K F F			
SPE C	K D I V T F Q E I D F K I R K Y L M D N Y K I Y - - D A - T S P Y V S G R I E I			
TSST-1	K K Q L A I S T L D F E I R H Q L T Q I H G L Y - - R S S D K T G G Y W K I			
ETA	K L E L I G Y P F D H K V N Q M H R S E I E L T L S R G L R Y Y G F T V P G N			
ETB	K Y S L L G Y P Y N Y S A Y S L Y Q S Q I E M F N D S - - Q Y F G Y T E V G N			

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	210	220	230	240
SEA	H T S T E P S V N Y D L F G A Q G Q Y S N T - - L L R I Y R D N K T I N S E - N			
SEE	H S S E G S T V S Y D L F D A Q G Q Y P D T - - L L R I Y R D N K T I N S E - N			
SED	D S S D G S K V S Y D L F D V K G D F P E - - K Q L R I Y S D N K T L S T E - H			
SEB	I E N E - N S F W Y D L M P A P G D K F D Q S K Y L M N Y N D N K M V D S K - D			
SEC1	I E N N G N T F W Y D L M P A P G D K F D Q S K Y L M M Y N D N K T V D S K - S			
SEC3	I E N N G N T F W Y D L M P A P G D K F D Q S K Y L M M Y N D N K T V D S K - S			
SPE A	I P K N K E S F W F D L F P E P - E F T - Q S K Y L M I Y K D N E T L D S N - T			
SPE C	G T K D G K H E Q I D L F D S P N E G T - R S D I F A K Y K D N R I I N M K N F			
TSST-1	T M N D G S T Y Q S D L S K F - E Y N - T E K P P I N I D E I K T I E A E I N *			
ETA	S G S G I F N S N G E L V G I H S S - - - - - K V S H L D R			
ETB	S G S G I F N L K G E L I G I H S G K G Q M N L P I G V F F N R K I S S L Y S			

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FIG. 1D

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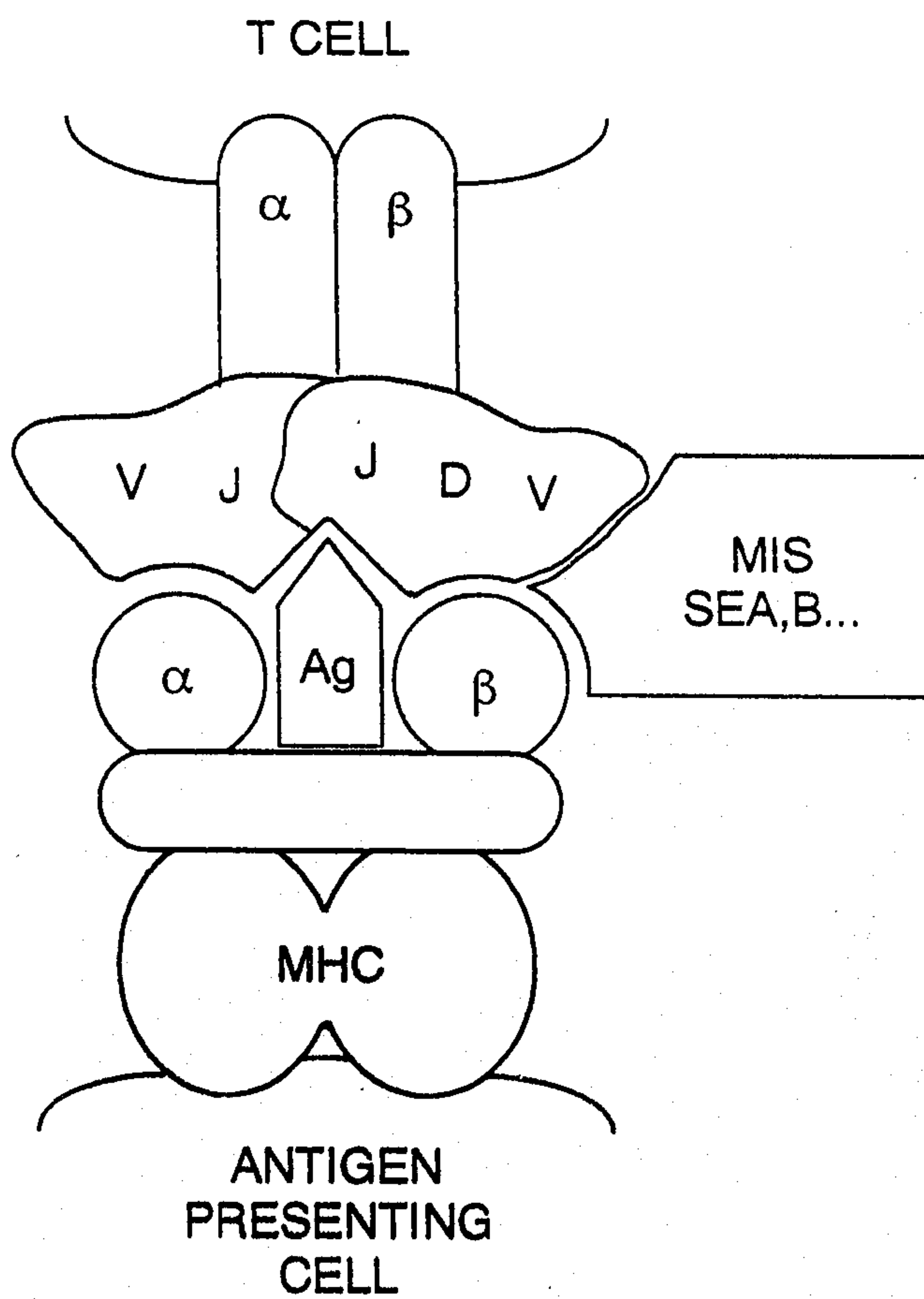
SEA M H I D I Y L Y T S *
SEE M H I D I Y L Y T T *
SED L H I D I Y L Y E K *
SEB V K I E V Y L T Y K K *
SECI V K I E V H L T T K N G *
SEC3 V K I E V H L T T K N G *

SPE A S Q I E V Y L T T K *
SPE C S H F D I Y L - E K *
TSST-1

ETA E H Q I N Y G V G I G N Y V - K R I I N E K N
ETB V D N T - F G D T L G N D L K K R A K L D K *

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**FIG. 3**