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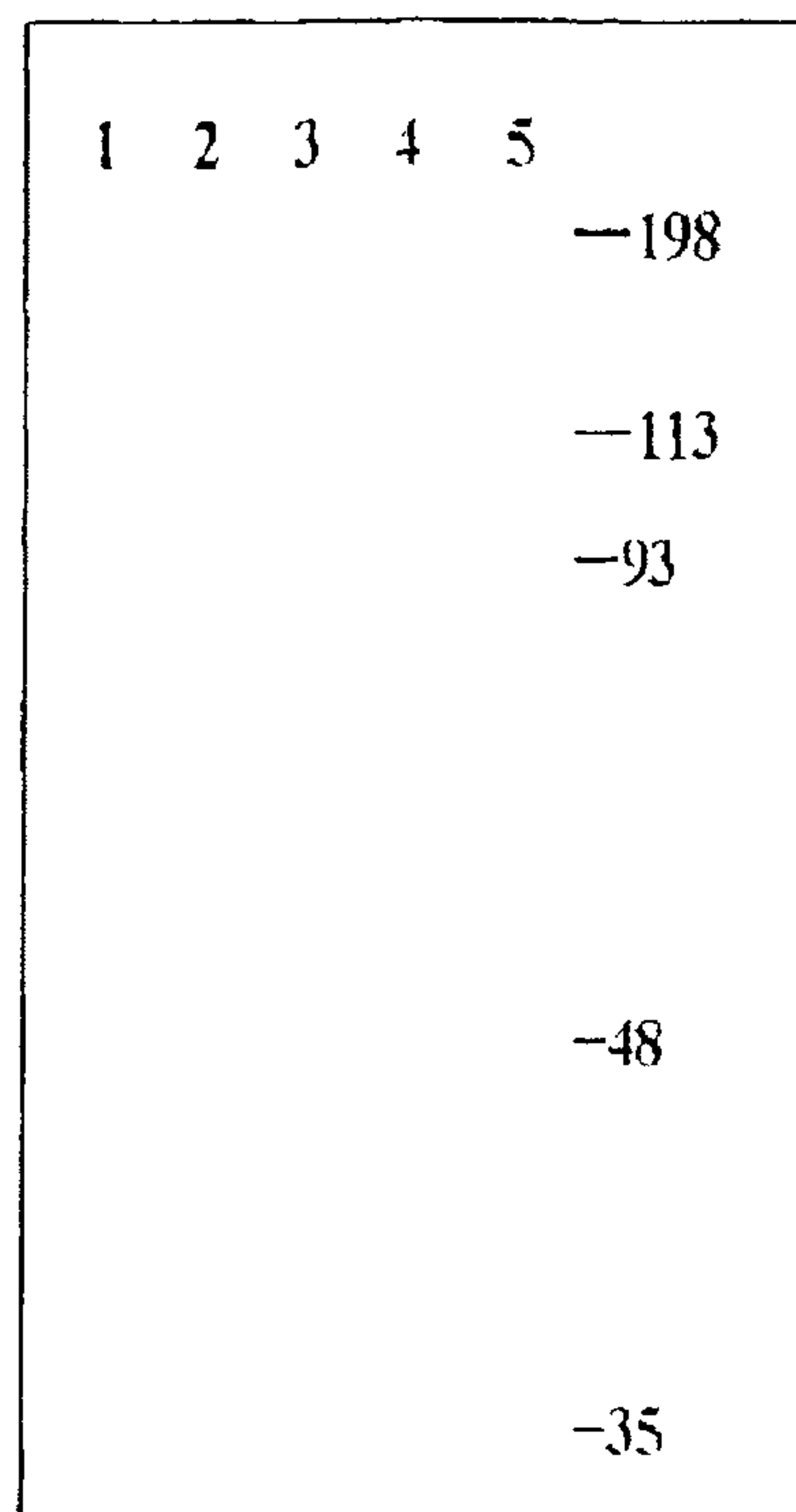
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(54) Titre : NOUVELLES PROTEINES IMMUNOGENES DE LEPTOSPIRA

(54) Title: NOVEL IMMUNOGENIC PROTEINS OF LEPTOSPIRA



(57) Abrégé/Abstract:

The invention provides novel immunogenic proteins LigA and LigB from *Leptospira* for use in the development of effective vaccines and antibodies, as well as improved diagnostic methods and kits.

Abstract

The invention provides novel immunogenic proteins LigA and LigB from *Leptospira* for use in the development of effective vaccines and antibodies, as well as improved diagnostic methods and kits.

Novel Immunogenic Proteins of *Leptospira*

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Related Application

This application claims priority to U.S. Provisional Patent application Serial No. 60/417,721, filed October 10, 2002, the entirety of which is incorporated herein by reference.

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Background of the Invention

Leptospirosis is a worldwide zoonotic disease caused by gram-negative spirochetes belonging to the genus *Leptospira*. Leptospirosis is prevalent in humans, horses, cattle and wild animals. The disease occurs widely in developing countries, such as Brazil and India, and is re-emerging in developed countries. Although the incidence of leptospirosis in humans in the United States is relatively low, disease incidence in domestic animals has increased in recent years.

Manifestations and routes of *Leptospira* infection vary depending on the host. Humans, who contract leptospirosis either directly or indirectly through contact with infected animals or a contaminated environment, often develop kidney and liver failure (Schubert, G. E. et al., Munch Med Wochenschr, 113:80-86 (1971); Bain, B. J. et al., Arch. Intern. Med., 131:740-745 (1973); Garcia, M. et al., Med. Clin. (Barc), 73:362-366 (1979); San Segundo, D., Med. Clin. (Barc), 78:28-31 (1982); Winearls, C. G. et al., Q J Med., 53:487-495 (1984); Menzies, D. G. et al., Scott Med. J., 34:410 (1989); Divers, T. J. et al., J. Am. Vet. Med. Assoc., 201:1391-1392 (1992); Petros, S. et al., Scand. J. Infect. Dis., 32:104-105 (2000); Kager, P. A. et al., Ned Tijdschr Geneeskd, 145:184-186 (2001)). *Leptospira* infection in humans can range in severity from an inapparent infection to death from renal or hepatic failure (Feigin, R. D. and D. C. Anderson, CRC Crit. Rev. Clin. Lab. Sci., 5:413-467 (1975)). In addition to hepatic and renal failure, uveitis is sometimes a sequela to *Leptospira* infection (Rathinam, S. R. et al., Am. J. Ophthalmol., 124:71-79 (1997)).

In animals such as horses, cattle, dogs and swine, infection causes abortion, still birth, renal failure, and uveitis (Akkermans, J. P., Bull. Off. Int. Epizoot., 66:849-866 (1966); Ellis, W. A. et al., Vet. Rec., 99:458-459 (1976); Ryan, T. J. et al., NZ Vet. J., 25:352 (1977); Ellis, W. A. et al., Vet. Rec., 103:237-239 (1978); Andreani, E. et al., Br. Vet. J., 139:165-170 (1983); Ellis, W. A. et al., Vet. Rec., 112:291-293 (1983); Elder, J. K. et al., Aust. Vet. J., 62:258-262 (1985); Ellis, W. A. et al., Vet. Rec., 118:294-295 (1986); Rocha, T., Vet. Rec., 126:602 (1990); Bolin, C. A. et al., J. Vet. Diagn. Invest., 3:152-154 (1991); Donahue, J. M. et al., J. Vet. Diagn. Invest., 3:148-151 (1991); Christianson, W. T., Vet. Clin. North Am. Food Anim. Pract., 8:623-639 (1992); Donahue, J. M. et al., J. Vet. Diagn. Invest., 4:279-284 (1992); Bernard, W. V. et al., J. Am. Vet. Med. Assoc., 202:1285-1286 (1993); Broll, S. et al., Zentralbl Veterinarmed [B], 40:641-653 (1993); Donahue, J. M. et al., J. Vet. Diagn. Invest., 7:87-91 (1995); Donahue, J. M. and Williams, N. M., Vet. Clin. North Am. Equine Pract., 16:443-456 (2000)) and can result in multi-organ failure. In horses, the most common manifestations of infection are abortion and uveitis (Poonacha, K. B. et al., Vet. Pathol., 30:362-369 (1993)). The association of leptospires with equine recurrent uveitis (ERU) (Halliwell, R. E. et al., Curr. Eye Res., 4:1033-1040 (1985)) has been well documented and the organism has been detected in ocular fluids by culture and PCR (Roberts, S. J., J. Amer. Vet. Med. Assoc., 175:803-808 (1958)). In addition, Parma et al. demonstrated reactivity of several bands in extracts of equine cornea and lens with anti-leptospiral sera by western blotting (Parma, A. E. et al., Vet. Immunol. Immunopathol., 14:181-185 (1987); Parma, A. E. et al., Vet. Immunol. Immunopathol., 10:215-224 (1985)). Although there is a strong association between leptospiral infection and uveitis, the immunopathogenesis of *Leptospira*-associated uveitis remains obscure.

Currently available leptospiral vaccines have low efficacy, are serovar specific and generally produce only short-term immunity in domestic livestock. In fact, these vaccines do not provide cross protection against the 250 known serovars of pathogenic *Leptospira*. Efforts to identify immunogenic components of value in vaccines have resulted in characterization of 31, 32, 36 and 41 kDa outer membrane proteins (Haake, D. A. et al., J. Bacteriol., 175:4225-4234

(1993); Haake, D. A. et al., Infect. Immun., 68:2276-2285 (2000); Haake, D. A. et al., Infect. Immun., 66:1579-1587 (1998); Haake, D. A. et al., Infect. Immun., 67:6572-6582 (1999); Shang, E. S. et al., Infect. Immun., 65:3174-3181 (1995); Shang, E. S. et al., Infect. Immun., 64:2322-2330 (1996)). Two of these proteins
 5 (31 and 41 kDa) function synergistically in immunoprotection of hamsters suggesting that an effective protein based vaccine would contain several components (Haake, D. A. et al., Infect. Immun., 68:2276-2285 (2000)). The search for protective immunogens is complicated by the possibility that important components may be produced only during infection. Supporting this
 10 possibility are recent studies that indicate that some immunogenic proteins of *L. interrogans* serovar pomona are upregulated at 37°C (Nally, J. E. et al., Infect. Immun., 69:400-404 (2001)).

Thus, there is an ongoing need for novel immunogenic proteins of *Leptospira* to aid in the development of effective vaccines and antibodies, as
 15 well as improved diagnostic methods and kits.

Summary of the Invention

The present invention provides an isolated and purified polynucleotide comprising a nucleic acid sequence encoding *ligA* from *Leptospira interrogans*.
 20 Also provided by the present invention is the polynucleotide comprising SEQ ID NO: 1.

The invention further provides an isolated and purified polynucleotide comprising a nucleic acid sequence encoding *ligB* from *Leptospira interrogans*. Also provided by the present invention is the polynucleotide comprising SEQ ID
 25 NO: 3 and SEQ ID NO: 45.

An isolated and purified polypeptide comprising a LigA polypeptide from *Leptospira interrogans* is provided by the present invention. The polypeptide comprising SEQ ID NO: 2 is also provided by the present invention

The present invention provides an isolated and purified polypeptide
 30 comprising a LigB polypeptide from *Leptospira interrogans*. Further, the invention provides the polypeptide comprising SEQ ID NO: 4 and SEQ ID NO: 46.

The present invention provides a pharmaceutical composition comprising a purified polypeptide from *Leptospira*, and a pharmaceutically acceptable carrier, wherein the composition is capable of eliciting an immune response against *Leptospira interrogans*. The polypeptide in the pharmaceutical composition of the present invention may comprise the polypeptides LigA or LigB. The pharmaceutical composition of the present invention may also optionally comprise an effective amount of an immunological adjuvant.

The present invention provides a vaccine comprising an immunogenic amount of a purified polypeptide from *Leptospira*, wherein the polypeptide is present in an amount that is effective to immunize a susceptible mammal against *Leptospira* infection in combination with a physiologically acceptable, non-toxic vehicle.

The polypeptide in the vaccine of the present invention may be LigA or LigB. The vaccine may also comprise an effective amount of an immunological adjuvant, and may be administered orally, mucosally, or by subcutaneous or intramuscular injection.

Further provided by the present invention is a method of eliciting an immune response in a subject against *Leptospira interrogans*, comprising administering to a subject the pharmaceutical composition described hereinabove. Another method provided by the present invention is a method of preventing *Leptospira interrogans* infections comprising administering to a subject the pharmaceutical composition described hereinabove.

The present invention additionally provides a method of protecting a susceptible mammal against *Leptospira* infection or colonization comprising administering to the mammal an effective amount of a vaccine comprising an immunogenic amount of *Leptospira* protein LigA or LigB wherein the amount of LigA or LigB is effective to immunize the susceptible mammal against *Leptospira* in combination with a physiologically-acceptable, non-toxic vehicle.

The present invention provides a composition comprising an amount of an immunologically active protein comprising SEQ ID NO:2, SEQ ID NO: 4, at least 9 amino acids of SEQ ID NO: 2, or at least 9 amino acids of SEQ ID NO: 4, and a pharmaceutically acceptable carrier, which amount is effective to stimulate the formation of antibodies against *Leptospira interrogans* in a

mammal, e.g., a human. Further provided by the present invention is a composition comprising an amount of an immunologically active protein comprising SEQ ID NO: 2, SEQ ID NO: 4, SEQ ID NO: 46, at least 9 amino acids of SEQ ID NO: 2, at least 9 amino acids of SEQ ID NO: 4, or at least 9 amino acids of SEQ ID NO: 46, which amount is effective to immunize a susceptible mammal against infection caused by *Leptospira*. The invention also provides that a composition as described in this paragraph is effective as a vaccine. The invention additionally provides that a composition as described in this paragraph further comprises an effective amount of an immune stimulating agent.

The present invention provides a method of stimulating the formation of antibodies against *Leptospira*, comprising administering to a mammal a composition comprising an effective amount of an immunologically active protein having SEQ ID NO: 2, SEQ ID NO: 4, SEQ ID NO: 46, at least 9 amino acids of SEQ ID NO: 2, at least 9 amino acids of SEQ ID NO: 4, or at least 9 amino acids of SEQ ID NO: 46. The composition as described in this paragraph may further comprise an effective amount of an immune stimulating agent. The present invention also provides that the composition as described in this paragraph is effective as a vaccine.

Further provided by the present invention is an assay kit for detecting antibodies against *Leptospira* strains which contains at least one immunologically active purified protein derived from *Leptospira interrogans* wherein such protein is characterized in that it elicits an immunological response from a mammal, has been prepared by expression in a bacterium other than *Leptospira interrogans*, is free of other *Leptospira interrogans* proteins; and is a protein having SEQ ID NO: 2, SEQ ID NO: 4, SEQ ID NO: 46, at least 9 amino acids of SEQ ID NO: 2, at least 9 amino acids of SEQ ID NO: 4, or at least 9 amino acids of SEQ ID NO: 46, which protein reacts with the antibodies present in a test fluid, and wherein said kit has at least one indicator component which detects complexes of immunologically active protein and antibody. The indicator component of the assay kit of the present invention is an antibody which is directed against the antibody to be detected and which has a label. The assay kit of the present invention contains a label, which comprises a radioactive

isotope, or an enzyme, such as peroxidase, which is able to catalyze a color or light reaction.

The present invention further provides that the immunologically active protein in the assay kit is biotinylated, and the indicator component is avidin or streptavidin having an enzyme covalently bonded thereto. The present invention provides an ELISA assay kit. The present invention provides an assay kit as described hereinabove, wherein the at least one immunologically active protein is coupled to microtiter plates, and the indicator component comprises anti-human immunoglobulin to which an enzyme catalyzing a color reaction is coupled. The present invention also provides an assay kit as described hereinabove, wherein the indicator component comprises IgG antibodies, IgM antibodies or a mixture thereof.

Provided by the present invention is a method for the detection of *Leptospira* infection, comprising the steps of contacting LigA protein from *Leptospira interrogans* with a biological sample from a mammal suspected of having *Leptospira* infection, wherein the LigA protein is characterized in that it is a protein having SEQ ID NO: 2, or at least 9 amino acids of SEQ ID NO: 2, and detecting the presence or absence of a complex formed between LigA and antibodies in the biological sample.

Further provided by the present invention is a method for the detection of *Leptospira* infection, comprising the steps of contacting LigB protein from *Leptospira interrogans* with a biological sample from a mammal suspected of having *Leptospira* infection, wherein the LigB protein is characterized in that it is a protein having SEQ ID NO: 4, SEQ ID NO: 46, at least 9 amino acids of SEQ ID NO: 4, or at least 9 amino acids of SEQ ID NO: 46, and detecting the presence or absence of a complex formed between LigB and antibodies in the biological sample.

Additionally provided by the present invention is an antibody specific for the purified LigA polypeptide and the purified LigB polypeptide, as described hereinabove. The present invention further provides for monoclonal or polyclonal antibodies, and the methods of making monoclonal or polyclonal antibodies.

In accordance with one aspect of the present invention there is provided an isolated and purified polynucleotide comprising a nucleic acid sequence encoding *ligB* from *Leptospira interrogans*, wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of 9 or more contiguous amino acids of SEQ ID NO: 46.

In accordance with a further aspect of the present invention there is provided an isolated and purified polypeptide comprising a LigB polypeptide from *Leptospira interrogans*, wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of 9 or more contiguous amino acids of SEQ ID NO: 46.

In accordance with a further aspect of the present invention there is provided a pharmaceutical composition comprising:

- (a) a purified LigB polypeptide from *Leptospira*, wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of 9 or more contiguous amino acids of SEQ ID NO: 46; and
- (b) a pharmaceutically acceptable carrier, wherein the composition is capable of eliciting an immune response against *Leptospira interrogans*.

In accordance with a further aspect of the present invention there is provided a vaccine comprising an immunogenic amount of a purified LigB polypeptide from *Leptospira* in combination with a physiologically acceptable, nontoxic vehicle; wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of 9 or more contiguous amino acids of SEQ ID NO: 46; and wherein the amount of LigB polypeptide is effective to immunize a mammal susceptible to *Leptospira* infection or colonization.

In accordance with a further aspect of the present invention there is provided a use of an effective amount of a vaccine for protecting a susceptible mammal against *Leptospira* infection or colonization, the vaccine comprising an immunogenic amount of a purified LigB polypeptide from *Leptospira* in combination with a physiologically acceptable, nontoxic vehicle; wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of 9 or more contiguous amino acids of SEQ ID NO: 46; and wherein the amount of LigB polypeptide is

effective to immunize a mammal susceptible to *Leptospira* infection or colonization.

In accordance with a further aspect of the present invention there is provided a composition comprising a pharmaceutically acceptable carrier and an amount of an immunologically active protein comprising SEQ ID NO: 4, SEQ ID NO:34, or a polypeptide that consists of 9 or more contiguous amino acids of SEQ ID NO: 46, and which amount is effective to stimulate the formation of antibodies against *Leptospira interrogans* in a person.

In accordance with a further aspect of the present invention there is provided a composition comprising a pharmaceutically acceptable carrier and an amount of an immunologically active protein comprising SEQ ID NO: 4, SEQ ID NO:34, or a polypeptide that consists of 9 or more contiguous amino acids of SEQ ID NO: 46, and which amount is effective to immunize a susceptible mammal against infection caused by *Leptospira*.

In accordance with a further aspect of the present invention there is provided a use of a composition comprising an effective amount of an immunologically active protein having SEQ ID NO: 4, having SEQ ID NO:34, or consisting of 9 or more contiguous amino acids of SEQ ID NO: 46 and at least one pharmaceutically acceptable excipient, for stimulating the formation of antibodies against *Leptospira*.

In accordance with a further aspect of the present invention there is provided an assay kit for detecting antibodies against *Leptospira* strains, wherein the assay kit contains at least one immunologically active purified LigB protein derived from *Leptospira interrogans*, wherein such protein is characterized in that it:

- a. elicits an immunological response from a mammal;
- b. has been prepared by expression in a bacterium other than *Leptospira interrogans*;
- c. is free of other *Leptospira interrogans* proteins; and
- d. is a protein having SEQ ID NO: 4, having SEQ ID NO:34, or consisting of 9 or more contiguous amino acids of SEQ ID NO: 46, which protein reacts with the antibodies present in a test fluid, and wherein said kit has at least one indicator component which detects complexes of immunologically active protein and antibody.

In accordance with a further aspect of the present invention there is provided a method for the detection of *Leptospira* infection in a mammal, comprising the steps of:

- (a) contacting LigB protein from *Leptospira interrogans* with a biological sample from a mammal suspected of having *Leptospira* infection, wherein the LigB protein is

a protein having SEQ ID NO: 4, having SEQ ID NO:34, or consisting of 9 or more contiguous amino acids of SEQ ID NO: 46, and

(b) detecting the presence or absence of a complex formed between LigB and antibodies in the biological sample, thereby indicating pathogenic *Leptospira* infection in the mammal, wherein the presence of a complex formed between LigB protein and antibodies in the biological sample indicates *Leptospira* infection in the mammal.

In accordance with a further aspect of the present invention there is provided an isolated and purified polynucleotide, wherein the polynucleotide: (i) comprises a nucleic acid sequence encoding a LigB polypeptide from *Leptospira interrogans*, wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (ii) consists of 27 or more contiguous nucleotides of SEQ ID NO: 45; with the proviso that the polynucleotide does not consist of the polynucleotide set forth in GenBank Accession No. AF325820.

In accordance with a further aspect of the present invention there is provided an isolated and purified LigB polypeptide from *Leptospira interrogans*, wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of 9 or more contiguous amino acids of SEQ ID NO: 46.

In accordance with a further aspect of the present invention there is provided a composition comprising a pharmaceutically acceptable carrier and an amount of: (a) an immunologically active protein comprising SEQ ID NO: 4 or SEQ ID NO:34, or (b) an immunologically active polypeptide that consists of 9 or more contiguous amino acids of SEQ ID NO: 46, and which amount is effective to stimulate the formation of antibodies against *Leptospira interrogans* in a mammal.

In accordance with a further aspect of the present invention there is provided a composition comprising a pharmaceutically acceptable carrier and an amount of: (a) an immunologically active protein comprising SEQ ID NO: 4 or SEQ ID NO:34, or (b) an immunologically active polypeptide that consists of 9 or more contiguous amino acids of SEQ ID NO: 46, and which amount is effective to immunize a susceptible mammal against infection caused by *Leptospira*.

In accordance with a further aspect of the present invention there is provided an isolated and purified polynucleotide, wherein the polynucleotide: (i) comprises a nucleic acid sequence encoding a LigB polypeptide from *Leptospira interrogans*, wherein the LigB

polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (ii) consists of SEQ ID NO: 45.

In accordance with a further aspect of the present invention there is provided a pharmaceutical composition comprising: (i) a purified LigB polypeptide from *Leptospira*, wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of SEQ ID NO: 46; and (ii) a pharmaceutically acceptable carrier, wherein the composition is capable of eliciting an immune response against *Leptospira interrogans*.

In accordance with a further aspect of the present invention there is provided a vaccine comprising an immunogenic amount of a purified LigB polypeptide from *Leptospira* in combination with a physiologically acceptable, nontoxic vehicle; wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of SEQ ID NO: 46; and wherein the amount of LigB polypeptide is effective to immunize a mammal susceptible to *Leptospira* infection or colonization.

In accordance with a further aspect of the present invention there is provided a use of an effective amount of a vaccine for protecting a susceptible mammal against *Leptospira* infection or colonization, the vaccine comprising an immunogenic amount of a purified LigB polypeptide from *Leptospira* in combination with a physiologically acceptable, nontoxic vehicle; wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of SEQ ID NO: 46; and wherein the amount of LigB polypeptide is effective to immunize a mammal susceptible to *Leptospira* infection or colonization.

In accordance with a further aspect of the present invention there is provided a composition comprising a pharmaceutically acceptable carrier and an amount of: (a) an immunologically active protein comprising SEQ ID NO: 4 or SEQ ID NO:34, or (b) an immunologically active polypeptide that consists of SEQ ID NO: 46, and which amount is effective to stimulate the formation of antibodies against *Leptospira interrogans* in a mammal.

In accordance with a further aspect of the present invention there is provided a composition comprising a pharmaceutically acceptable carrier and an amount of: (a) an immunologically active protein comprising SEQ ID NO: 4 or SEQ ID NO:34, or (b) an immunologically active polypeptide that consists of SEQ ID NO: 46, and which amount is effective to immunize a susceptible mammal against infection caused by *Leptospira*.

In accordance with a further aspect of the present invention there is provided a use of a composition comprising an effective amount of an immunologically active protein comprising SEQ ID NO: 4, comprising SEQ ID NO:34, or consisting of SEQ ID NO: 46 and at least one pharmaceutically acceptable excipient, for stimulating the formation of antibodies against *Leptospira*.

In accordance with a further aspect of the present invention there is provided an assay kit for detecting antibodies against *Leptospira* strains, wherein the assay kit contains at least one immunologically active purified LigB protein derived from *Leptospira interrogans*, wherein such protein is characterized in that it: a. elicits an immunological response from a mammal; b. has been prepared by expression in a bacterium other than *Leptospira interrogans*; c. is free of other *Leptospira interrogans* proteins; and d. is a protein comprising SEQ ID NO: 4, comprising SEQ ID NO:34, or consisting of SEQ ID NO: 46, which protein reacts with the antibodies present in a test fluid, and wherein said kit has at least one indicator component which detects complexes of immunologically active protein and antibody.

In accordance with a further aspect of the present invention there is provided a method for the detection of *Leptospira* infection in a mammal, comprising the steps of: (a) contacting LigB protein from *Leptospira interrogans* with a biological sample from a mammal suspected of having *Leptospira* infection, wherein the LigB protein is a protein comprising SEQ ID NO: 4, comprising SEQ ID NO:34, or consisting of SEQ ID NO: 46, and (b) detecting the presence or absence of a complex formed between LigB and antibodies in the biological sample, thereby indicating pathogenic *Leptospira* infection in the mammal, wherein the presence of a complex formed between LigB protein and antibodies in the biological sample indicates *Leptospira* infection in the mammal.

Brief Description of the Drawings

Fig. 1. Nucleotide sequence of *ligA* (SEQ ID NO: 1) and its deduced amino acid sequence (SEQ ID NO: 2). Bold regions are the three possible translation start codons. Underlined nucleotides indicate primer annealing sites
 5 for Figs. 3 and 7, respectively. Arrows show the potential transcription termination sequence.

Fig. 2. Alignment of the predicted amino acid sequences for the twelve tandem repeats (SEQ ID NOs: 5-16) and the immunoglobulin-like domain of *E. coli* intimin binding (receptor) protein (Igl1, CD: pfam02368 (SEQ ID NO: 17);
 10 Igl2, CD: smart00635 (SEQ ID NO: 18)). Twelve repeat sequences of a 90 amino acid sequence are from 136-218, 224-310, 311-400, 401-489, 490-580, 581-670, 671-760, 761-851, 852-942, 943-1033, 1034-1125 and 1126-1216, respectively.

Fig 3. Expression of LigA in *E. coli*. Whole cell lysates of *E. coli* were
 15 subjected to SDS-PAGE, transferred to nitrocellulose and blotted with a 1:100 dilution of rabbit antiserum to the 90 kDa truncated LigA. Lanes 1 & 2. *E. coli* with vector, pET22b only. Lanes 3 & 4. *E. coli* harboring pET22b plus *ligA* construct. Lanes 2 & 4. *E. coli* was induced with 0.4 mM IPTG. Lane 5. Pre-stained molecular size markers (Bio-Rad, CA).

20 Fig. 4. LipL32 and LipL36 but not LigA expression are temperature regulated. Lane 1. Whole cell lysate of leptospires grown at 30°C. Lanes 2, 3, 4, 5 and 6 represent 2, 3, 4, 5 and 6 day old cultures, respectively, of leptospires grown at 37°C. Each lane was loaded with ~5.0 µg of proteins.

Fig. 5. LigA expression in hamsters infected with *L. interrogans* serovar pomona. Sections of kidney were treated with rabbit antiserum specific for a 90 kDa truncated LigA (A) *L. interrogans* serovar pomona (B), LipL32 (C), LipL36 (D) and with pre-immune serum (E). Kidney sections from non-infected hamsters were unreactive. Bar = 67 µm.
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Fig. 6. Recombinant LigA protein purified using metal affinity
 30 chromatography and subjected to SDS-PAGE separation was probed with normal horse sera (first 4 lanes), equine lyme disease positive sera (lanes 5-9), human granulocytic ehrlichiosis positive sera (lanes 10-11), aborted mare sera

(lanes 12-19), and rabbit serum specific for a 90 kDa truncated LigA (lane 20). Each lane was loaded with ~ 0.5 µg of protein.

Fig. 7. Agarose gel showing PCR products and restriction analysis of *ligA* from different pathogenic serovars of *Leptospira* (A) PCR products of *ligA* (B) *Hind*III digested PCR product of *ligA*. Lane 1. *L. interrogans* serovar pomona type kennewicki, 2. *L. interrogans* serovar pomona, 3. *L. interrogans* serovar hardjo, 4. *L. interrogans* serovar icterohemorrhagiae, 5. *L. kirchneri* serovar grippotyphosa, 6. *L. interrogans* serovar wolfii.

Fig. 8. Nucleotide sequences of the *ligB* (SEQ ID NO:3) and its deduced amino acid sequence (SEQ ID NO:4). Bold represents three possible start codons and Italics indicate the potential ribosome-binding site. The predicted signal sequence of LigB is underlined. Serine rich region and a possible tyrosine kinase phosphorylation are earmarked in dotted lines and double underlined. Waveline indicates the homology region with IBD of Tir-intimin complex. The Genbank accession number for the nucleotide sequence of *ligB* is AF368236.

Fig. 9. Comparison of the structural domains of LigB with LigA from *L. interrogans* serovar pomona invasin from *Yersinia* and intimin from *E. coli*. Dark and dotted boxes represent the Ig-like domain and C type lectin like domain. LysM represents lysing motif in *E. coli*. ORFU shows the open reading frame present in Tir and Intimin of *E. coli*.

Fig. 10. Alignment of twelve repeats of 90 amino acid sequence of LigB (SEQ ID NOs:19-30) and its homology with the bacterial Ig-like domain from Pfam (Ig1 (SEQ ID NO:31) and Ig2 (SEQ ID NO:32)). Gaps have been introduced to optimize alignment among the polypeptides.

Fig. 11. (A) Alignment of C-terminal variation regions of LigB (SEQ ID NO:33) and LigA (SEQ ID NO:34).

Fig. 12. Nucleotide sequence of *ligB* (SEQ ID NO: 45) and its deduced amino acid sequence (SEQ ID NO: 46).

Fig. 13. A. Alignment of twelve repeats of 90 amino acid sequence of LigB indicate homology with the bacterial Ig-like domain from Pfam (Ig1 and Ig2). Gaps have been introduced to optimize alignment among the polypeptides. B. Alignment of variable regions of LigA and LigB.

Fig. 14. The presence of *lig* genes in different serovars of *Leptospira* was determined by Southern blot. The non-radioactively labeled conserved region of LigA and LigB were used to probe *Eco*RI digested genomic DNA from *Leptospira interrogans* serovars Pomona (Lane 1), Hardjo (Lane 2),
 5 Copenhageni (Lane 3), Grippotyphosa (Lane 4), Canicola (Lane 5), Wolffii (Lane 6), Autumnalis (Lane 7), Bataviae (Lane 8), Australis (Lane 9), and Pyrogenes (Lane 10). Non-pathogenic *L. biflexa* serovar Patoc does not contain the *lig* genes (Lane 11).

Fig. 15. Expression and purification of GST fusion proteins of LigA and
 10 LigB. LigA and LigB were truncated into conserved and variable regions cloned into plasmid pGEX4T-2 and expressed as GST fusion proteins. The fusion proteins were purified by affinity chromatography and subjected to SDS-PAGE. Expression and purification of the conserved regions of LigA and LigB (A); expression of Variable region of LigA (B); expression of Variable region of
 15 LigB (C). Lane 1. Molecular Marker (Bio-Rad, CA); lane 2. *E. coli* with vector, pGEX4T-2 only (control); lane 3, un-induced *E. coli* with recombinant construct; lane 4, IPTG induced *E. coli* with recombinant construct; lane 5, Affinity chromatography purified GST fusion proteins; lane 6, Thrombin digested GST fusion protein.

20 Fig. 16. Immunoblot showing lack of expression of LigA and LigB in leptospires. Whole cell lysates of low passage and high passage cultures of leptospires, purified recombinant GST fusion proteins and thrombin digested GST fusion protein were then subjected to SDS-PAGE and transferred to a nitrocellulose membrane. Membranes were then blotted with a 1:800 dilution of
 25 a rabbit antiserum to the variable region of LigA and LigB. 16A and 16B represent the expression of LigA and LigB respectively. Lane 1, *E. coli* with vector; lanes 2 and 4, uninduced and IPTG induced *E. coli* harboring recombinant construct; lane 3, Thrombin digested, purified GST fusion protein; lanes 5 and 6, Low passage and high passage leptospires; lane 7, pre-stained
 30 molecular marker (Bio-Rad, CA).

Fig. 17. Expression of *LigA* and *LigB* of leptospires at the transcript level. RNA from low and high passage cultures were subjected to one step RT-PCR with *ligA* and *ligB* specific primers. Fig 17A and B represent RT-PCR with

a *ligA* and a *ligB* specific primer, respectively; Lane 1, Marker (pBH20 digested with *HinfI*); lanes 2 and 3, RNA from Low and high passage cultures; lane 4, genomic DNA from the leptospires (positive control); lane 5, control (RNA without RT in the reaction).

5 Fig. 18. Reactivity of vaccinated sera to whole cell proteins of leptospires. Whole cell proteins of leptospires were subjected to SDS-PAGE, transferred to nitrocellulose membrane and probed with a 1:10 dilution of pre- and post-vaccinated sera. Lane 1. Pre-vaccinated sera; lane 2. Grippopomona Vaccinated sera; lanes 4 and 5. Naturally infected sera from dogs.

10 Fig. 19. KELA with recombinant antigens of LigA and LigB to MAT positive canine sera. Figures 19A, B and C represent the reactivity of KELA using recombinant proteins from conserved regions of LigA and LigB (Con), variable region of LigA (VarA) and variable region of LigB (VarB) to MAT positive canine sera respectively. ♦ Represents the reactivity of each sample.

15 Descriptive statistics was used to determine the cut off value for KELA units and the maximum reactivity of sera from healthy dogs was considered as the cut off value (KELA cut off value for Con, VarA and VarB was 7, 42 and 42 respectively).

20 Detailed Description of the Invention

I. Leptospira

Leptospira organisms are very thin, tightly coiled, obligate aerobic spirochetes characterized by a unique flexuous type of motility. *Leptospira* is a gram-negative spirochete with internal flagella. The genus is divided into two species: the pathogenic leptospires *L. interrogans* and the free-living leptospire *L. biflexa*. Serotypes of *L. interrogans* are the agents of leptospirosis, a zoonotic disease.

Leptospira enters the host through mucosa and broken skin, resulting in bacteremia. The spirochetes multiply in organs, most commonly the central nervous system, kidneys, and liver. They are cleared by the immune response from the blood and most tissues but persist and multiply for some time in the kidney tubules. Infective bacteria are shed in the urine. The mechanism of tissue damage is not known.

The primary hosts for this disease are wild and domestic animals, and the disease is a major cause of economic loss in the meat and dairy industry.

Humans are accidental hosts in whom this disseminated disease varies in severity from subclinical to fatal. Humans acquire the infection by contact with the urine of infected animals. Human-to-human transmission is very rare. The first human case of leptospirosis was described in 1886 as a severe icteric illness and was referred to as Weil's disease; however, most human cases of leptospirosis are nonicteric and are not life-threatening. Recovery usually follows the appearance of a specific antibody.

Clinical diagnosis is usually confirmed by serology. Isolation of spirochetes is possible, but it is time-consuming and requires special media. Serum antibodies are responsible for host resistance.

Clinical manifestations of leptospirosis are associated with a general febrile disease and are not sufficiently characteristic for diagnosis. As a result, leptospirosis often is initially misdiagnosed as meningitis or hepatitis. Typically, the disease is biphasic, which an acute leptospiremic phase followed by the immune leptospiruric phase. The three organ systems most frequently involved are the central nervous system, kidneys, and liver. After an average incubation period of 7 to 14 days, the leptospiremic acute phase is evidenced by abrupt onset of fever, severe headache, muscle pain, and nausea; these symptoms persist for approximately 7 days. Jaundice occurs during this phase in more severe infections. With the appearance of antileptospiral antibodies, the acute phase of the disease subsides and leptospires can no longer be isolated from the blood. The immune leptospiruric phase occurs after an asymptomatic period of several days. It is manifested by a fever of shorter duration and central nervous system involvement (meningitis). Leptospires appear in the urine during this phase and are shed for various periods depending on the host.

Leptospira has the general structural characteristics that distinguish spirochetes from other bacteria. The cell is encased in a three- to five-layer outer membrane or envelope. Beneath this outer membrane are the flexible, helical peptidoglycan layer and the cytoplasmic membrane; these encompass the cytoplasmic contents of the cell. The structures surrounded by the outer membrane are collectively called the protoplasmic cylinder. An unusual feature

of the spirochetes is the location of the flagella, which lie between the outer membrane and the peptidoglycan layer. They are referred to as periplasmic flagella. The periplasmic flagella are attached to the protoplasmic cylinder subterminally at each end and extend toward the center of the cell. The number
 5 of periplasmic flagella per cell varies among the spirochetes. The motility of bacteria with external flagella is impeded in viscous environments, but that of spirochetes is enhanced. The slender (0.1 μm by 8 to 20 μm) leptospire are tightly coiled, flexible cells. In liquid media, one or both ends are usually hooked. Leptospire are too slender to be visualized with the bright-field
 10 microscope, but are clearly seen by dark-field or phase microscopy. They do not stain well with aniline dyes.

The leptospire have two periplasmic flagella, one originating at each end of the cell. The free ends of the periplasmic flagella extend toward the center of the cell, but do not overlap as they do in other spirochetes. The basal bodies of
 15 *Leptospira* periplasmic flagella resemble those of Gram-negative bacteria, whereas those of other spirochetes are similar to the basal bodies of Gram-positive bacteria. *Leptospira* differs from other spirochetes in that they are lacking lycolipids and having diaminopimelic acid rather than ornithine in its peptidoglycan.

20 The leptospire are the most readily cultivated of the pathogenic spirochetes. They have relatively simple nutritional requirements; long-chain fatty acids and vitamins B1 and B12 are the only organic compounds known to be necessary for growth. When cultivated in media of pH 7.4 at 30°C, their average generation time is about 12 hours. Aeration is required for maximal
 25 growth. They can be cultivated in plates containing soft (1 percent) agar medium, in which they form primarily subsurface colonies.

The two species, *L. interrogans* and *L. biflexa*, are further divided into serotypes based on their antigenic composition. More than 200 serotypes have been identified in *L. interrogans*. The most prevalent serotypes in the United
 30 States are canicola, grippityphosa, hardjo, icterohaemorrhagiae, and pomona. Genetic studies have demonstrated that serologically diverse serotypes may be present in the same genetic group. At least seven species of pathogenic leptospire have been identified by nucleotide analysis.

The mucosa and broken skin are the most likely sites of entry for the pathogenic leptospires. A generalized infection ensues, but no lesion develops at the site of entry. Bacteremia occurs during the acute, leptospiremic phase of the disease. The host responds by producing antibodies that, in combination with
 5 complement, are leptospiricidal. The leptospires are rapidly eliminated from all host tissues except the brain, eyes, and kidneys. Leptospires surviving in the brain and eyes multiply slowly if at all; however, in the kidneys they multiply in the convoluted tubules and are shed in the urine (the leptospiruric phase). The leptospires may persist in the host for weeks to months; in rodents they may be
 10 shed in the urine for the lifetime of the animal. Leptospiruric urine is the vehicle of transmission of this disease.

The mechanism by which leptospires cause disease remains unresolved, as neither endotoxins nor exotoxins have been associated with them. The marked contrast between the extent of functional impairment in leptospirosis and
 15 the scarcity of histologic lesions suggests that most damage occurs at the subcellular level. Damage to the endothelial lining of the capillaries and subsequent interference with blood flow appear responsible for the lesions associated with leptospirosis. The most notable feature of severe leptospirosis is the progressive impairment of hepatic and renal function. Renal failure is the
 20 most common cause of death. The lack of substantial cell destruction in leptospirosis is reflected in the complete recovery of hepatic and renal function in survivors. Although spontaneous abortion is common in infected cattle and swine, only recently has a human case of fatal congenital leptospirosis been documented.

25 The host's immunologic response to leptospirosis is thought to be responsible for lesions associated with the late phase of this disease; this helps to explain the ineffectiveness of antibiotics once symptoms of the disease have been present for 4 days or more.

Nonspecific host defenses appear ineffective against the virulent
 30 leptospires, which are rapidly killed *in vitro* by the antibody-complement system; virulent strains are more resistant to this leptospiricidal activity than are avirulent strains. Immunity to leptospirosis is primarily humoral; cell-mediated immunity does not appear to be important, but may be responsible for some of

the late manifestations of the disease. Immunity to leptospirosis is serotype specific and may persist for years. Immune serum has been used to treat human leptospirosis and passively protects experimental animals from the disease. The survival of leptospires within the convoluted tubules of the kidneys may be
 5 related to the ineffectiveness of the antibody-complement system at this site. Previously infected animals can become seronegative and continue to shed leptospires in their urine, possibly because of the lack of antigenic stimulation by leptospires in the kidneys.

Because clinical manifestations of leptospirosis are too variable and
 10 nonspecific to be diagnostically useful, microscopic demonstration of the organisms, serologic tests, or both are used in diagnosis. The microscopic agglutination test is most frequently used for serodiagnosis. The organisms can be isolated from blood or urine on commercially available media, but the test must be requested specifically because special media is needed. Isolation of the
 15 organisms confirms the diagnosis.

Reducing its prevalence in wild and domestic animals can control human leptospirosis. Although little can be done about controlling the disease in wild animals, leptospirosis in domestic animals can be controlled through vaccination with inactivated whole cells or an outer membrane preparation. If vaccines do
 20 not contain a sufficient immunogenic mass, the resulting immune response protects the host against clinical disease, but not against development of the renal shedder state. Because a multiplicity of serotypes may exist in a given geographic region and the protection afforded by the inactivated vaccines is serotype specific, the use of polyvalent vaccines is usually recommended.

25 Although the leptospires are susceptible to antibiotics such as penicillin and tetracycline *in vitro*, use of these drugs in the treatment of leptospirosis is somewhat controversial. Treatment is most effective if initiated within a week of disease onset. At later times, immunologic damage may already have begun, rendering antimicrobial therapy less effective. Doxycycline has been used
 30 successfully as a chemoprophylactic agent for military personnel training in tropical areas.

II. LigA and LigB

The *ligA* (SEQ ID NO: 1) and *ligB* (SEQ ID NO:3, SEQ ID NO:45) encode Leptospiral immunoglobulin (Ig)-like protein A and B (LigA and LigB) from *Leptospira interrogans* serovar pomona type kennewicki and have
 5 molecular masses of approximately 130 and 140 kDa, respectively.

LigA has twelve or more repeats of a 90 amino acid motif homologous with bacterial Ig-like domains such as intimins of *E. coli*, invasins of *Yersinia* and a cell surface protein of *C. acetobutylicum* (Palaniappan, R. U. M. et al., Infect. Immun., 70:5924-5930 (2002)).

10 The complete nucleotide sequence of a novel *ligB* is homologous with *ligA* of *Leptospira*, and cell adhesion proteins such as intimin of *E. coli* and a cell adhesion protein of *C. acetobutylicum*.

III. Definitions

15 The term “chimeric” refers to any gene or DNA that contains 1) DNA sequences, including regulatory and coding sequences, that are not found together in nature, or 2) sequences encoding parts of proteins not naturally adjoined, or 3) parts of promoters that are not naturally adjoined. Accordingly, a
 20 chimeric gene may comprise regulatory sequences and coding sequences that are derived from different sources, or comprise regulatory sequences and coding sequences derived from the same source, but arranged in a manner different from that found in nature.

“Expression” refers to the transcription and/or translation of an
 25 endogenous gene or a transgene in a host cell. For example, in the case of antisense constructs, expression may refer to the transcription of the antisense DNA only. In addition, expression refers to the transcription and stable accumulation of sense (mRNA) or functional RNA. Expression may also refer to the production of protein.

30 The term “gene” is used broadly to refer to any segment of nucleic acid associated with a biological function. Thus, genes include coding sequences and/or the regulatory sequences required for their expression. For example, gene refers to a nucleic acid fragment that expresses mRNA, or specific protein, including regulatory sequences. Genes also include nonexpressed DNA

segments that, for example, form recognition sequences for other proteins.

Genes can be obtained from a variety of sources, including cloning from a source of interest or synthesizing from known or predicted sequence information, and may include sequences designed to have desired parameters.

5 A “transgene” refers to a gene that has been introduced into the genome by transformation and is stably maintained. Transgenes may include, for example, DNA that is either heterologous or homologous to the DNA of a particular cell to be transformed. Additionally, transgenes may comprise native genes inserted into a non-native organism, or chimeric genes. The term
10 “endogenous gene” refers to a native gene in its natural location in the genome of an organism. A “foreign” or “exogenous” gene refers to a gene not normally found in the host organism but that is introduced by gene transfer.

 The invention encompasses isolated or substantially purified nucleic acid compositions. In the context of the present invention, for example, an “isolated”
15 or “purified” DNA molecule is a DNA molecule that exists apart from its native environment and is therefore not a product of nature. An isolated DNA molecule may exist in a purified form or may exist in a non-native environment such as, for example, a transgenic host cell. For example, an “isolated” or “purified” nucleic acid molecule, or biologically active portion thereof, is
20 substantially free of other cellular material, or culture medium when produced by recombinant techniques, or substantially free of chemical precursors or other chemicals when chemically synthesized. In one embodiment, an “isolated” nucleic acid is free of sequences that naturally flank the nucleic acid (*i.e.*, sequences located at the 5' and 3' ends of the nucleic acid) in the genomic DNA
25 of the organism from which the nucleic acid is derived. For example, in various embodiments, the isolated nucleic acid molecule can contain less than about 5 kb, 4 kb, 3 kb, 2 kb, 1 kb, 0.5 kb, or 0.1 kb of nucleotide sequences that naturally flank the nucleic acid molecule in genomic DNA of the cell from which the nucleic acid is derived. Fragments and variants of the disclosed nucleotide
30 sequences and proteins or partial-length proteins encoded thereby are also encompassed by the present invention. By “fragment” or “portion” is meant a full length, or less than full length, of the nucleotide sequence encoding, or the amino acid sequence of, a polypeptide or protein.

A “mutation” refers to an insertion, deletion or substitution of one or more nucleotide bases of a nucleic acid sequence, so that the nucleic acid sequence differs from the wild-type sequence. For example, a “point” mutation refers to an alteration in the sequence of a nucleotide at a single base position
 5 from the wild type sequence.

The term “nucleic acid” refers to deoxyribonucleotides or ribonucleotides and polymers thereof in either single- or double-stranded form, composed of monomers (nucleotides) containing a sugar, phosphate and a base which is either a purine or pyrimidine. Unless specifically limited, the term encompasses
 10 nucleic acids containing known analogs of natural nucleotides that have similar binding properties as the reference nucleic acid and are metabolized in a manner similar to naturally occurring nucleotides. Unless otherwise indicated, a particular nucleic acid sequence also implicitly encompasses conservatively modified variants thereof (*e.g.*, degenerate codon substitutions) and
 15 complementary sequences as well as the sequence explicitly indicated. Specifically, degenerate codon substitutions may be achieved by generating sequences in which the third position of one or more selected (or all) codons is substituted with mixed-base and/or deoxyinosine residues (Batzer et al., Nucl. Acids Res., 19:508 (1991); Ohtsuka et al., JBC, 260:2605 (1985); Rossolini et
 20 al., Mol. Cell. Probes, 8:91 (1994). A “nucleic acid fragment” is a fraction of a given nucleic acid molecule. Deoxyribonucleic acid (DNA) in the majority of organisms is the genetic material while ribonucleic acid (RNA) is involved in the transfer of information contained within DNA into proteins. The term “nucleotide sequence” refers to a polymer of DNA or RNA that can be single- or
 25 double-stranded, optionally containing synthetic, non-natural or altered nucleotide bases capable of incorporation into DNA or RNA polymers. The terms “nucleic acid,” “nucleic acid molecule,” “nucleic acid fragment,” “nucleic acid sequence,” or “polynucleotide” may also be used interchangeably with gene, cDNA, DNA and RNA encoded by a gene (Batzer et al., 1991; Ohtsuka et
 30 al., 1985; Rossolini et al., 1999).

“Operably linked” when used with respect to nucleic acid, means joined as part of the same nucleic acid molecule, suitably positioned and oriented for transcription to be initiated from the promoter. DNA operably linked to a

promoter is under transcriptional initiation regulation of the promoter. Coding sequences can be operably-linked to regulatory sequences in sense or antisense orientation.

“Promoter” refers to a nucleotide sequence, usually upstream (5') to its coding sequence, which controls the expression of the coding sequence by providing the recognition for RNA polymerase and other factors required for proper transcription. “Promoter” includes a minimal promoter that is a short DNA sequence comprised of, for example, a TATA- box, a -35, -10 polymerase binding site and/or a ribosome binding site (Shine-Dolgarno sequence), and other sequences that serve to specify the site of transcription initiation, to which regulatory elements are added for control of expression. “Promoter” also refers to a nucleotide sequence that includes a minimal promoter plus regulatory elements that is capable of controlling the expression of a coding sequence or functional RNA. This type of promoter sequence consists of proximal and more distal upstream elements, the latter elements often referred to as enhancers. Accordingly, an “enhancer” is a DNA sequence that can stimulate promoter activity and may be an innate element of the promoter or a heterologous element inserted to enhance the level or tissue specificity of a promoter. It is capable of operating in both orientations (normal or flipped), and is capable of functioning even when moved either upstream or downstream from the promoter. Both enhancers and other upstream promoter elements bind sequence-specific DNA-binding proteins that mediate their effects. Promoters may be derived in their entirety from a native gene, or be composed of different elements derived from different promoters found in nature, or even be comprised of synthetic DNA segments. A promoter may also contain DNA sequences that are involved in the binding of protein factors that control the effectiveness of transcription initiation in response to physiological or developmental conditions.

The “initiation site” is the position surrounding the first nucleotide that is part of the transcribed sequence, which is also defined as position +1. With respect to this site all other sequences of the gene and its controlling regions are numbered. Downstream sequences (*i.e.*, further protein encoding sequences in the 3' direction) are denominated positive, while upstream sequences (mostly of the controlling regions in the 5' direction) are denominated negative.

Promoter elements, particularly a TATA element, a -35, -10 polymerase binding site and/or a ribosome binding site (Shine-Dalgarno sequence), that are inactive or that have greatly reduced promoter activity in the absence of upstream activation are referred to as “minimal or core promoters.” In the presence of a suitable transcription factor, the minimal promoter functions to permit transcription. A “minimal or core promoter” thus consists only of all basal elements needed for transcription initiation, *e.g.*, a TATA box, a -35, -10 polymerase binding site, a ribosome binding site (Shine-Dalgarno sequence), and/or an initiator.

“Constitutive expression” refers to expression using a constitutive or regulated promoter. “Conditional” and “regulated expression” refer to expression controlled by a regulated promoter. An “inducible promoter” is a regulated promoter that can be turned on in a cell by an external stimulus, such as a chemical, light, hormone, stress, or a pathogen.

The following terms are used to describe the sequence relationships between two or more nucleic acids or polynucleotides: (a) “reference sequence,” (b) “comparison window,” (c) “sequence identity,” (d) “percentage of sequence identity,” and (e) “substantial identity.”

(a) As used herein, “reference sequence” is a defined sequence used as a basis for sequence comparison. A reference sequence may be a subset or the entirety of a specified sequence; for example, as a segment of a full-length cDNA or gene sequence, or the complete cDNA or gene sequence.

(b) As used herein, “comparison window” makes reference to a contiguous and specified segment of a polynucleotide sequence, wherein the polynucleotide sequence in the comparison window may comprise additions or deletions (*i.e.*, gaps) compared to the reference sequence (which does not comprise additions or deletions) for optimal alignment of the two sequences. Generally, the comparison window is at least 20 contiguous nucleotides in length, and optionally can be 30, 40, 50, 100, or longer. Those of skill in the art understand that to avoid a high similarity to a reference sequence due to inclusion of gaps in the polynucleotide sequence a gap penalty is typically introduced and is subtracted from the number of matches.

Methods of alignment of sequences for comparison are well known in the art. Thus, the determination of percent identity between any two sequences can be accomplished using a mathematical algorithm. Preferred, non-limiting examples of such mathematical algorithms are the algorithm of Myers and Miller, CABIOS, 4:11 (1988); the local homology algorithm of Smith et al., Adv. Appl. Math., 2:482 (1981); the homology alignment algorithm of Needleman and Wunsch, JMB, 48:443 (1970); the search-for-similarity-method of Pearson and Lipman, Proc. Natl. Acad. Sci. USA, 85:2444 (1988); the algorithm of Karlin and Altschul, Proc. Natl. Acad. Sci. USA, 87:2264 (1990),
 5 modified as in Karlin and Altschul, Proc. Natl. Acad. Sci. USA, 90:5873 (1993).
 10

Computer implementations of these mathematical algorithms can be utilized for comparison of sequences to determine sequence identity. Such implementations include, but are not limited to: CLUSTAL in the PC/Gene program (available from Intelligenetics, Mountain View, California); the ALIGN
 15 program (Version 2.0) and GAP, BESTFIT, BLAST, FASTA, and TFASTA in the Wisconsin Genetics Software Package, Version 8 (available from Genetics Computer Group (GCG), 575 Science Drive, Madison, Wisconsin, USA). Alignments using these programs can be performed using the default parameters. The CLUSTAL program is well described by Higgins et al., Gene, 73:237
 20 (1988); Higgins et al., CABIOS, 5:151 (1989); Corpet et al., Nucl. Acids Res., 16:10881 (1988); Huang et al., CABIOS, 8:155 (1992); and Pearson et al., Meth. Mol. Biol., 24:307 (1994). The ALIGN program is based on the algorithm of Myers and Miller, *supra*. The BLAST programs of Altschul et al., JMB, 215:403 (1990); Nucl. Acids Res., 25:3389 (1990), are based on the algorithm of
 25 Karlin and Altschul *supra*.

Software for performing BLAST analyses is publicly available through the National Center for Biotechnology Information, which is available on the world wide web at ncbi.nlm.nih.gov. This algorithm involves first identifying high scoring sequence pairs (HSPs) by identifying short words of length W in
 30 the query sequence, which either match or satisfy some positive-valued threshold score T when aligned with a word of the same length in a database sequence. T is referred to as the neighborhood word score threshold. These initial neighborhood word hits act as seeds for initiating searches to find longer HSPs

containing them. The word hits are then extended in both directions along each sequence for as far as the cumulative alignment score can be increased.

Cumulative scores are calculated using, for nucleotide sequences, the parameters M (reward score for a pair of matching residues; always > 0) and N (penalty score for mismatching residues; always < 0). For amino acid sequences, a scoring matrix is used to calculate the cumulative score. Extension of the word hits in each direction are halted when the cumulative alignment score falls off by the quantity X from its maximum achieved value, the cumulative score goes to zero or below due to the accumulation of one or more negative-scoring residue alignments, or the end of either sequence is reached.

In addition to calculating percent sequence identity, the BLAST algorithm also performs a statistical analysis of the similarity between two sequences. One measure of similarity provided by the BLAST algorithm is the smallest sum probability ($P(N)$), which provides an indication of the probability by which a match between two nucleotide or amino acid sequences would occur by chance. For example, a test nucleic acid sequence is considered similar to a reference sequence if the smallest sum probability in a comparison of the test nucleic acid sequence to the reference nucleic acid sequence is less than about 0.1, more preferably less than about 0.01, and most preferably less than about 0.001.

To obtain gapped alignments for comparison purposes, Gapped BLAST (in BLAST 2.0) can be utilized as described in Altschul et al., Nucleic Acids Res. 25:3389 (1997). Alternatively, PSI-BLAST (in BLAST 2.0) can be used to perform an iterated search that detects distant relationships between molecules. See Altschul et al., *supra*. When utilizing BLAST, Gapped BLAST, PSI-BLAST, the default parameters of the respective programs (*e.g.* BLASTN for nucleotide sequences, BLASTX for proteins) can be used. The BLASTN program (for nucleotide sequences) uses as defaults a wordlength (W) of 11, an expectation (E) of 10, a cutoff of 100, $M=5$, $N=-4$, and a comparison of both strands. For amino acid sequences, the BLASTP program uses as defaults a wordlength (W) of 3, an expectation (E) of 10, and the BLOSUM62 scoring matrix. See the world wide web at ncbi.nlm.nih.gov. Alignment may also be performed manually by inspection.

For purposes of the present invention, comparison of nucleotide sequences for determination of percent sequence identity to the promoter sequences disclosed herein is preferably made using the BlastN program (version 1.4.7 or later) with its default parameters or any equivalent program.

5 By “equivalent program” is intended any sequence comparison program that, for any two sequences in question, generates an alignment having identical nucleotide or amino acid residue matches and an identical percent sequence identity when compared to the corresponding alignment generated by the preferred program.

10 (c) As used herein, “sequence identity” or “identity” in the context of two nucleic acid or polypeptide sequences makes reference to a specified percentage of residues in the two sequences that are the same when aligned for maximum correspondence over a specified comparison window, as measured by sequence comparison algorithms or by visual inspection. When
15 percentage of sequence identity is used in reference to proteins it is recognized that residue positions which are not identical often differ by conservative amino acid substitutions, where amino acid residues are substituted for other amino acid residues with similar chemical properties (*e.g.*, charge or hydrophobicity) and therefore do not change the functional properties of the molecule. When
20 sequences differ in conservative substitutions, the percent sequence identity may be adjusted upwards to correct for the conservative nature of the substitution. Sequences that differ by such conservative substitutions are said to have “sequence similarity” or “similarity.” Means for making this adjustment are well known to those of skill in the art. Typically this involves scoring a
25 conservative substitution as a partial rather than a full mismatch, thereby increasing the percentage sequence identity. Thus, for example, where an identical amino acid is given a score of 1 and a non-conservative substitution is given a score of zero, a conservative substitution is given a score between zero and 1. The scoring of conservative substitutions is calculated, *e.g.*, as
30 implemented in the program PC/GENE (Intelligenetics, Mountain View, California).

(d) As used herein, “percentage of sequence identity” means the value determined by comparing two optimally aligned sequences over a

comparison window, wherein the portion of the polynucleotide sequence in the comparison window may comprise additions or deletions (*i.e.*, gaps) as compared to the reference sequence (which does not comprise additions or deletions) for optimal alignment of the two sequences. The percentage is
 5 calculated by determining the number of positions at which the identical nucleic acid base or amino acid residue occurs in both sequences to yield the number of matched positions, dividing the number of matched positions by the total number of positions in the window of comparison, and multiplying the result by 100 to yield the percentage of sequence identity.

10 (e)(i) The term “substantial identity” of polynucleotide sequences means that a polynucleotide comprises a sequence that has at least 70%, 71%, 72%, 73%, 74%, 75%, 76%, 77%, 78%, or 79%, preferably at least 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, or 89%, more preferably at least 90%, 91%, 92%, 93%, or 94%, and most preferably at least 95%, 96%, 97%, 98%, or
 15 99% sequence identity, compared to a reference sequence using one of the alignment programs described using standard parameters. One of skill in the art will recognize that these values can be appropriately adjusted to determine corresponding identity of proteins encoded by two nucleotide sequences by taking into account codon degeneracy, amino acid similarity, reading frame
 20 positioning, and the like. Substantial identity of amino acid sequences for these purposes normally means sequence identity of at least 70%, more preferably at least 80%, 90%, and most preferably at least 95%. Another indication that nucleotide sequences are substantially identical is if two molecules hybridize to each other under stringent conditions (see below). Generally, stringent
 25 conditions are selected to be about 5°C lower than the thermal melting point (T_m) for the specific sequence at a defined ionic strength and pH. However, stringent conditions encompass temperatures in the range of about 1°C to about 20°C, depending upon the desired degree of stringency as otherwise qualified herein. Nucleic acids that do not hybridize to each other under stringent
 30 conditions are still substantially identical if the polypeptides they encode are substantially identical. This may occur, *e.g.*, when a copy of a nucleic acid is created using the maximum codon degeneracy permitted by the genetic code. One indication that two nucleic acid sequences are substantially identical is

when the polypeptide encoded by the first nucleic acid is immunologically cross reactive with the polypeptide encoded by the second nucleic acid.

(e)(ii) The term “substantial identity” in the context of a peptide indicates that a peptide comprises a sequence with at least 70%, 71%, 72%, 73%, 74%, 75%, 76%, 77%, 78%, or 79%, preferably 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, or 89%, more preferably at least 90%, 91%, 92%, 93%, or 94%, or even more preferably, 95%, 96%, 97%, 98% or 99%, sequence identity to the reference sequence over a specified comparison window. Preferably, optimal alignment is conducted using the homology alignment algorithm of Needleman and Wunsch, *J. Mol. Biol.* 48:443 (1970). An indication that two peptide sequences are substantially identical is that one peptide is immunologically reactive with antibodies raised against the second peptide. Thus, a peptide is substantially identical to a second peptide, for example, where the two peptides differ only by a conservative substitution.

For sequence comparison, typically one sequence acts as a reference sequence to which test sequences are compared. When using a sequence comparison algorithm, test and reference sequences are input into a computer, subsequence coordinates are designated if necessary, and sequence algorithm program parameters are designated. The sequence comparison algorithm then calculates the percent sequence identity for the test sequence(s) relative to the reference sequence, based on the designated program parameters.

As noted above, another indication that two nucleic acid sequences are substantially identical is that the two molecules hybridize to each other under stringent conditions. The phrase “hybridizing specifically to” refers to the binding, duplexing, or hybridizing of a molecule only to a particular nucleotide sequence under stringent conditions when that sequence is present in a complex mixture (e.g., total cellular) DNA or RNA. “Bind(s) substantially” refers to complementary hybridization between a probe nucleic acid and a target nucleic acid and embraces minor mismatches that can be accommodated by reducing the stringency of the hybridization media to achieve the desired detection of the target nucleic acid sequence.

“Stringent hybridization conditions” and “stringent hybridization wash conditions” in the context of nucleic acid hybridization experiments such as

Southern and Northern hybridizations are sequence dependent, and are different under different environmental parameters. Longer sequences hybridize specifically at higher temperatures. The thermal melting point (T_m) is the temperature (under defined ionic strength and pH) at which 50% of the target sequence hybridizes to a perfectly matched probe. Specificity is typically the function of post-hybridization washes, the critical factors being the ionic strength and temperature of the final wash solution. For DNA-DNA hybrids, the T_m can be approximated from the equation of Meinkoth and Wahl, Anal. Biochem., 138:267 (1984); $T_m = 81.5^\circ\text{C} + 16.6 (\log M) + 0.41 (\%GC) - 0.61 (\% \text{ form}) - 500/L$; where M is the molarity of monovalent cations, $\%GC$ is the percentage of guanosine and cytosine nucleotides in the DNA, $\% \text{ form}$ is the percentage of formamide in the hybridization solution, and L is the length of the hybrid in base pairs. T_m is reduced by about 1°C for each 1% of mismatching; thus, T_m , hybridization, and/or wash conditions can be adjusted to hybridize to sequences of the desired identity. For example, if sequences with $>90\%$ identity are sought, the T_m can be decreased 10°C . Generally, stringent conditions are selected to be about 5°C lower than the T_m for the specific sequence and its complement at a defined ionic strength and pH. However, severely stringent conditions can utilize a hybridization and/or wash at 1, 2, 3, or 4°C lower than the T_m ; moderately stringent conditions can utilize a hybridization and/or wash at 6, 7, 8, 9, or 10°C lower than the T_m ; low stringency conditions can utilize a hybridization and/or wash at 11, 12, 13, 14, 15, or 20°C lower than the T_m . Using the equation, hybridization and wash compositions, and desired temperature, those of ordinary skill will understand that variations in the stringency of hybridization and/or wash solutions are inherently described. If the desired degree of mismatching results in a temperature of less than 45°C (aqueous solution) or 32°C (formamide solution), it is preferred to increase the SSC concentration so that a higher temperature can be used. An extensive guide to the hybridization of nucleic acids is found in Tijssen, Laboratory Techniques in Biochemistry and Molecular Biology Hybridization with Nucleic Acid Probes, part I chapter 2 "Overview of principles of hybridization and the strategy of nucleic acid probe assays" Elsevier, New York (1993). Generally, highly

stringent hybridization and wash conditions are selected to be about 5°C lower than the T_m for the specific sequence at a defined ionic strength and pH.

An example of highly stringent wash conditions is 0.15 M NaCl at 72°C for about 15 minutes. An example of stringent wash conditions is a 0.2X SSC wash at 65°C for 15 minutes (see, Sambrook, *infra*, for a description of SSC buffer). Often, a high stringency wash is preceded by a low stringency wash to remove background probe signal. An example medium stringency wash for a duplex of, *e.g.*, more than 100 nucleotides, is 1X SSC at 45°C for 15 minutes. An example low stringency wash for a duplex of, *e.g.*, more than 100 nucleotides, is 4-6X SSC at 40°C for 15 minutes. For short probes (*e.g.*, about 10 to 50 nucleotides), stringent conditions typically involve salt concentrations of less than about 1.5 M, more preferably about 0.01 to 1.0 M, Na ion concentration (or other salts) at pH 7.0 to 8.3, and the temperature is typically at least about 30°C and at least about 60°C for long probes (*e.g.*, >50 nucleotides). Stringent conditions may also be achieved with the addition of destabilizing agents such as formamide. In general, a signal to noise ratio of 2X (or higher) than that observed for an unrelated probe in the particular hybridization assay indicates detection of a specific hybridization. Nucleic acids that do not hybridize to each other under stringent conditions are still substantially identical if the proteins that they encode are substantially identical. This occurs, *e.g.*, when a copy of a nucleic acid is created using the maximum codon degeneracy permitted by the genetic code.

Very stringent conditions are selected to be equal to the T_m for a particular probe. An example of stringent conditions for hybridization of complementary nucleic acids which have more than 100 complementary residues on a filter in a Southern or Northern blot is 50% formamide, *e.g.*, hybridization in 50% formamide, 1 M NaCl, 1% SDS at 37°C, and a wash in 0.1X SSC at 60 to 65°C. Exemplary low stringency conditions include hybridization with a buffer solution of 30 to 35% formamide, 1M NaCl, 1% SDS (sodium dodecyl sulphate) at 37°C, and a wash in 1X to 2X SSC (20X SSC = 3.0 M NaCl/0.3 M trisodium citrate) at 50 to 55°C. Exemplary moderate stringency conditions

include hybridization in 40 to 45% formamide, 1.0 M NaCl, 1% SDS at 37°C, and a wash in 0.5X to 1X SSC at 55 to 60°C.

The terms "protein," "peptide" and "polypeptide" are used interchangeably herein. The term protein, as used herein, generally refers to a
 5 long, linear polymer of amino acids joined head to tail by a peptide bond between the carboxylic acid group of one amino acid and the amino group of the next.

As used herein, the term "immunogenic protein" refers to a protein that is capable of inducing a humoral and/or a cell-mediated immune response. A
 10 substance that induces a specific immune response may also be referred to as an "antigen," an "immunogen," or an "immunologically active protein."

As used herein, the term "leptospiral protein" includes variants or biologically active or inactive fragments of LigA or LigB from *Leptospira interrogans*. A "variant" of the polypeptide is a leptospiral protein that is not
 15 completely identical to a native leptospiral protein. A variant leptospiral protein can be obtained by altering the amino acid sequence by insertion, deletion, or substitution of one or more amino acid. The amino acid sequence of the protein is modified, for example by substitution, to create a polypeptide having substantially the same or improved qualities as compared to the native
 20 polypeptide. The substitution may be a conserved substitution. A "conserved substitution" is a substitution of an amino acid with another amino acid having a similar side chain. A conserved substitution would be a substitution with an amino acid that makes the smallest change possible in the charge of the amino acid or size of the side chain of the amino acid (alternatively, in the size, charge
 25 or kind of chemical group within the side chain) such that the overall peptide retains its spatial conformation but has altered biological activity. For example, common conserved changes might be Asp to Glu, Asn or Gln; His to Lys, Arg or Phe; Asn to Gln, Asp or Glu and Ser to Cys, Thr or Gly. Alanine is commonly used to substitute for other amino acids. The 20 essential amino acids can be
 30 grouped as follows: alanine, valine, leucine, isoleucine, proline, phenylalanine, tryptophan and methionine having nonpolar side chains; glycine, serine, threonine, cystine, tyrosine, asparagine and glutamine having uncharged polar side chains; aspartate and glutamate having acidic side chains; and lysine,

arginine, and histidine having basic side chains. Stryer, L. *Biochemistry* (2d edition) W. H. Freeman and Co. San Francisco (1981), p. 14-15; Lehninger, A. *Biochemistry* (2d ed., 1975), p. 73-75.

It is known that variant polypeptides can be obtained based on substituting certain amino acids for other amino acids in the polypeptide structure in order to modify or improve biological activity. For example, through substitution of alternative amino acids, small conformational changes may be conferred upon a polypeptide that result in increased bioactivity. Alternatively, amino acid substitutions in certain polypeptides may be used to provide residues that may then be linked to other molecules to provide peptide-molecule conjugates that retain sufficient properties of the starting polypeptide to be useful for other purposes.

One can use the hydropathic index of amino acids in conferring interactive biological function on a polypeptide, wherein it is found that certain amino acids may be substituted for other amino acids having similar hydropathic indices and still retain a similar biological activity. Alternatively, substitution of like amino acids may be made on the basis of hydrophilicity, particularly where the biological function desired in the polypeptide to be generated is intended for use in immunological embodiments. The greatest local average hydrophilicity of a protein, as governed by the hydrophilicity of its adjacent amino acids, correlates with its immunogenicity. U.S. Patent No. 4,554,101. Accordingly, it is noted that substitutions can be made based on the hydrophilicity assigned to each amino acid. In using either the hydrophilicity index or hydropathic index, which assigns values to each amino acid, it is preferred to conduct substitutions of amino acids where these values are ± 2 , with ± 1 being particularly preferred, and those with in ± 0.5 being the most preferred substitutions.

The variant leptospiral protein comprises at least seven amino acid residues, preferably about 20 to about 2000 residues, and more preferably about 50 to about 1000 residues, and even more preferably about 80 to about 200 residues, wherein the variant leptospiral protein has at least 50%, preferably at least about 80%, and more preferably at least about 90% but less than 100%, contiguous amino acid sequence homology or identity to the amino acid sequence of a corresponding native leptospiral protein.

The amino acid sequence of the variant leptospiral protein corresponds essentially to the native leptospiral protein amino acid sequence. As used herein "correspond essentially to" refers to a polypeptide sequence that will elicit a protective immunological response substantially the same as the response
 5 generated by native leptospiral protein. Such a response may be at least 60% of the level generated by native leptospiral protein, and may even be at least 80% of the level generated by native leptospiral protein. An immunological response to a composition or vaccine is the development in the host of a cellular and/or antibody-mediated immune response to the polypeptide or vaccine of interest.
 10 Usually, such a response consists of the subject producing antibodies, B cell, helper T cells, suppressor T cells, and/or cytotoxic T cells directed specifically to an antigen or antigens included in the composition or vaccine of interest.

A variant of the invention may include amino acid residues not present in the corresponding native leptospiral protein, or may include deletions relative to
 15 the corresponding native leptospiral protein. A variant may also be a truncated "fragment" as compared to the corresponding native leptospiral protein, *i.e.*, only a portion of a full-length protein. Leptospiral protein variants also include peptides having at least one D-amino acid.

The immunologically active proteins of the present invention are
 20 leptospiral proteins, as well as proteins, polypeptides, variants or fragments of LigA or LigB from *Leptospira interrogans*. The immunologically active proteins of the present invention may be of variable length, with the minimum fragment length comprising between 9-15 amino acids.

As used herein, a "transgenic," "transformed," or "recombinant" cell
 25 refers to a genetically modified or genetically altered cell, the genome of which comprises a recombinant DNA molecule or sequence ("transgene"). For example, a "transgenic cell" can be a cell transformed with a "vector." A "transgenic," "transformed," or "recombinant" cell thus refers to a host cell such as a bacterial or yeast cell into which a heterologous nucleic acid molecule has
 30 been introduced. The nucleic acid molecule can be stably integrated into the genome by methods generally known in the art (*e.g.*, disclosed in Sambrook and Russell, 2001). For example, "transformed," "transformant," and "transgenic" cells have been through the transformation process and contain a foreign or

exogenous gene. The term “untransformed” refers to cells that have not been through the transformation process.

The term “transformation” refers to the transfer of a nucleic acid fragment into the genome of a host cell, or the transfer into a host cell of a
 5 nucleic acid fragment that is maintained extrachromosomally.

“Vector” is defined to include, *inter alia*, any plasmid, cosmid, phage or other construct in double or single stranded linear or circular form that may or may not be self transmissible or mobilizable, and that can transform prokaryotic or eukaryotic host either by integration into the cellular genome or exist
 10 extrachromosomally, *e.g.*, autonomous replicating plasmid with an origin of replication. A vector can comprise a construct such as an expression cassette having a DNA sequence capable of directing expression of a particular nucleotide sequence in an appropriate host cell, comprising a promoter operably linked to the nucleotide sequence of interest that also is operably linked to
 15 termination signals. An expression cassette also typically comprises sequences required for proper translation of the nucleotide sequence. The expression cassette comprising the nucleotide sequence of interest may be chimeric, meaning that at least one of its components is heterologous with respect to at least one of its other components. The expression cassette may also be one that
 20 is naturally occurring but has been obtained in a recombinant form useful for heterologous expression. The expression of the nucleotide sequence in the expression cassette may be under the control of a constitutive promoter or of an inducible promoter that initiates transcription only when the host cell is exposed to some particular external stimulus.

25 The term “wild type” refers to an untransformed cell, *i.e.*, one where the genome has not been altered by the presence of the recombinant DNA molecule or sequence or by other means of mutagenesis. A “corresponding” untransformed cell is a typical control cell, *i.e.*, one that has been subjected to transformation conditions, but has not been exposed to exogenous DNA.

30 A “vaccine” is a compound or composition that will elicit a protective immunological response in an animal to which the vaccine has been administered. An immunological response to a vaccine is the development in the host of a cellular and/or antibody-mediated immune response to the polypeptide

or vaccine of interest. Usually, such a response consists of the subject producing antibodies, B cell, helper T cells, suppressor T cells, and/or cytotoxic T cells directed specifically to an antigen or antigens included in the composition or vaccine of interest.

5 As used herein, the term "therapeutic agent" refers to any agent or material that has a beneficial effect on the mammalian recipient. Thus, "therapeutic agent" embraces both therapeutic and prophylactic molecules having nucleic acid or protein components.

10 IV. Vaccine Preparations

The present invention provides a vaccine for use to protect mammals against *Leptospira* colonization or infection. For example, the vaccine may contain an immunogenic amount of isolated and purified *Leptospira* protein or cell in combination with a physiologically-acceptable, non-toxic vehicle.

15 Vaccines of the present invention can also include effective amounts of immunological adjuvants, known to enhance an immune response.

To immunize a subject, the immunogenic protein from *Leptospira* is administered parenterally, usually by intramuscular or subcutaneous injection in an appropriate vehicle. Other modes of administration, however, are also
20 acceptable. For example, the vaccine may be administered orally, or *via* a mucosal route, such as a nasal, gastrointestinal or genital site. Vaccine formulations will contain an effective amount of the active ingredient in a vehicle. The effective amount is sufficient to prevent, ameliorate or reduce the incidence of *Leptospira* infection in the target mammal. The effective amount is
25 readily determined by one skilled in the art. The active ingredient may typically range from about 1% to about 95% (w/w) of the composition, or even higher or lower if appropriate. The quantity to be administered depends upon factors such as the age, weight and physical condition of the animal considered for vaccination. The quantity also depends upon the capacity of the animal's
30 immune system to synthesize antibodies, and the degree of protection desired. Effective dosages can be readily established by one of ordinary skill in the art through routine trials establishing dose response curves. The subject is immunized by administration of the leptospiral vaccine in one or more doses.

Multiple doses may be administered as is required to maintain a state of immunity to *Leptospira*.

To prepare a vaccine, the immunogenic *Leptospira* protein or proteins can be isolated, lyophilized and stabilized. The vaccine may then be adjusted to an appropriate concentration, optionally combined with a suitable vaccine adjuvant, and packaged for use. Suitable adjuvants include but are not limited to surfactants, *e.g.*, hexadecylamine, octadecylamine, lysolecithin, dimethyldioctadecylammonium bromide, N,N-dioctadecyl-N'-N-bis(2-hydroxyethyl-propane di-amine), methoxyhexadecyl-glycerol, and pluronic polyols; polyanions, *e.g.*, pyran, dextran sulfate, poly IC, polyacrylic acid, carbopol; peptides, *e.g.*, muramyl dipeptide, MPL, aimethylglycine, tuftsin, oil emulsions, alum, and mixtures thereof. Other potential adjuvants include the B peptide subunits of *E. coli* heat labile toxin or of the cholera toxin. (McGhee et al., 1993). Finally, the immunogenic product may be incorporated into liposomes for use in a vaccine formulation, or may be conjugated to proteins such as keyhole limpet hemocyanin (KLH) or human serum albumin (HSA) or other polymers.

V. Antibodies

The antibodies of the invention are prepared by using standard techniques. To prepare polyclonal antibodies or "antisera," an animal is inoculated with an antigen, *i.e.*, a purified immunogenic protein from *Leptospira*, and then immunoglobulins are recovered from a fluid, such as blood serum, that contains the immunoglobulins, after the animal has had an immune response.

For inoculation, the antigen is preferably bound to a carrier peptide and emulsified using a biologically suitable emulsifying agent, such as Freund's incomplete adjuvant. A variety of mammalian or avian host organisms may be used to prepare polyclonal antibodies against *Leptospira*.

Following immunization, immunoglobulin is purified from the immunized bird or mammal, *e.g.*, goat, rabbit, mouse, rat, or donkey and the like. For certain applications, particularly certain pharmaceutical applications, it is preferable to obtain a composition in which the antibodies are essentially free of antibodies that do not react with the immunogen. This composition is

composed virtually entirely of the high titer, monospecific, purified polyclonal antibodies to the *Leptospira* protein.

Antibodies can be purified by affinity chromatography, using purified *Leptospira* protein. Purification of antibodies by affinity chromatography is generally known to those skilled in the art (see, for example, U.S. Patent No. 4,533,630). Briefly, the purified antibody is bound to a solid support for a sufficient time and under appropriate conditions for the antibody to bind to the polypeptide or peptide. Such time and conditions are readily determinable by those skilled in the art. The unbound, unreacted antibody is then removed, such as by washing. The bound antibody is then recovered from the column by eluting the antibodies, so as to yield purified, monospecific polyclonal antibodies.

Monoclonal antibodies can be also prepared, using known hybridoma cell culture techniques. In general, this method involves preparing an antibody-producing fused cell line, *e.g.*, of primary spleen cells fused with a compatible continuous line of myeloma cells, and growing the fused cells either in mass culture or in an animal species, such as a murine species, from which the myeloma cell line used was derived or is compatible. Such antibodies offer many advantages in comparison to those produced by inoculation of animals, as they are highly specific and sensitive and relatively "pure" immunochemically. Immunologically active fragments of the present antibodies are also within the scope of the present invention, *e.g.*, the $F_{(ab)}$ fragment scFv antibodies, as are partially humanized monoclonal antibodies.

Thus, it will be understood by those skilled in the art that the hybridomas herein referred to may be subject to genetic mutation or other changes while still retaining the ability to produce monoclonal antibody of the same desired specificity. The present invention encompasses mutants, other derivatives and descendants of the hybridomas.

It will be further understood by those skilled in the art that a monoclonal antibody may be subjected to the techniques of recombinant DNA technology to produce other derivative antibodies, humanized or chimeric molecules or antibody fragments that retain the specificity of the original monoclonal antibody. Such techniques may involve combining DNA encoding the

immunoglobulin variable region, or the complementarity determining regions (CDRs), of the monoclonal antibody with DNA coding the constant regions, or constant regions plus framework regions, of a different immunoglobulin, for example, to convert a mouse-derived monoclonal antibody into one having
 5 largely human immunoglobulin characteristics (see EP 184187A, 2188638A).

VI. Formulations of Vaccine Compounds and Methods of Administration

The vaccine compounds may be formulated as pharmaceutical
 10 compositions and administered to a mammalian host, such as a human patient, in a variety of forms adapted to the chosen route of administration, *i.e.*, orally or parenterally, by intravenous, intramuscular, topical or subcutaneous routes.

Thus, the present compounds may be systemically administered, *e.g.*, orally, in combination with a pharmaceutically acceptable vehicle such as an
 15 inert diluent or an assimilable edible carrier. They may be enclosed in hard or soft shell gelatin capsules, may be compressed into tablets, or may be incorporated directly with the food of the patient's diet. For oral therapeutic administration, the active compound may be combined with one or more excipients and used in the form of ingestible tablets, buccal tablets, troches,
 20 capsules, elixirs, suspensions, syrups, wafers, and the like. Such compositions and preparations should contain at least 0.1% of active compound. The percentage of the compositions and preparations may, of course, be varied and may conveniently be between about 2 to about 60% of the weight of a given unit dosage form. The amount of active compound in such therapeutically useful
 25 compositions is such that an effective dosage level will be obtained.

The tablets, troches, pills, capsules, and the like may also contain the following: binders such as gum tragacanth, acacia, corn starch or gelatin; excipients such as dicalcium phosphate; a disintegrating agent such as corn starch, potato starch, alginic acid and the like; a lubricant such as magnesium
 30 stearate; and a sweetening agent such as sucrose, fructose, lactose or aspartame or a flavoring agent such as peppermint, oil of wintergreen, or cherry flavoring may be added. When the unit dosage form is a capsule, it may contain, in addition to materials of the above type, a liquid carrier, such as a vegetable oil or

a polyethylene glycol. Various other materials may be present as coatings or to otherwise modify the physical form of the solid unit dosage form. For instance, tablets, pills, or capsules may be coated with gelatin, wax, shellac or sugar and the like. A syrup or elixir may contain the active compound, sucrose or fructose
5 as a sweetening agent, methyl and propylparabens as preservatives, a dye and flavoring such as cherry or orange flavor. Of course, any material used in preparing any unit dosage form should be pharmaceutically acceptable and substantially non-toxic in the amounts employed. In addition, the active compound may be incorporated into sustained-release preparations and devices.

10 The active compound may also be administered intravenously or intraperitoneally by infusion or injection. Solutions of the active compound or its salts may be prepared in water, optionally mixed with a nontoxic surfactant. Dispersions can also be prepared in glycerol, liquid polyethylene glycols, triacetin, and mixtures thereof and in oils. Under ordinary conditions of storage
15 and use, these preparations contain a preservative to prevent the growth of microorganisms.

The pharmaceutical dosage forms suitable for injection or infusion can include sterile aqueous solutions or dispersions or sterile powders comprising the active ingredient that are adapted for the extemporaneous preparation of sterile
20 injectable or infusible solutions or dispersions, optionally encapsulated in liposomes. In all cases, the ultimate dosage form should be sterile, fluid and stable under the conditions of manufacture and storage. The liquid carrier or vehicle can be a solvent or liquid dispersion medium comprising, for example, water, ethanol, a polyol (for example, glycerol, propylene glycol, liquid
25 polyethylene glycols, and the like), vegetable oils, nontoxic glyceryl esters, and suitable mixtures thereof. The proper fluidity can be maintained, for example, by the formation of liposomes, by the maintenance of the required particle size in the case of dispersions or by the use of surfactants. The prevention of the action of microorganisms can be brought about by various antibacterial and
30 antifungal agents, for example, parabens, chlorobutanol, phenol, sorbic acid, thimerosal, and the like. In many cases, it will be preferable to include isotonic agents, for example, sugars, buffers or sodium chloride. Prolonged absorption of

the injectable compositions can be brought about by the use in the compositions of agents delaying absorption, for example, aluminum monostearate and gelatin.

Sterile injectable solutions are prepared by incorporating the active compound in the required amount in the appropriate solvent, *e.g.*, an adjuvant,
5 with various of the other ingredients enumerated above, as required, followed by filter sterilization. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and the freeze drying techniques, which yield a powder of the active ingredient plus any additional desired ingredient present in the previously sterile-filtered
10 solutions.

For topical administration, the present compounds may be applied in pure form, *i.e.*, when they are liquids. However, it will generally be desirable to administer them to the skin as compositions or formulations, in combination with a dermatologically acceptable carrier, which may be a solid or a liquid.

15 Useful solid carriers include finely divided solids such as talc, clay, microcrystalline cellulose, silica, alumina and the like. Useful liquid carriers include water, alcohols or glycols or water-alcohol/glycol blends, in which the present compounds can be dissolved or dispersed at effective levels, optionally with the aid of non-toxic surfactants. Adjuvants such as fragrances and
20 additional antimicrobial agents can be added to optimize the properties for a given use. The resultant liquid compositions can be applied from absorbent pads, used to impregnate bandages and other dressings, or sprayed onto the affected area using pump-type or aerosol sprayers.

Thickeners such as synthetic polymers, fatty acids, fatty acid salts and
25 esters, fatty alcohols, modified celluloses or modified mineral materials can also be employed with liquid carriers to form spreadable pastes, gels, ointments, soaps, and the like, for application directly to the skin of the user.

Examples of useful dermatological compositions that can be used to deliver the compounds of the present invention to the skin are known to the art;
30 for example, see Jacquet et al. (U.S. Patent No. 4,608,392), Geria (U.S. Pat. No. 4,992,478), Smith et al. (U.S. Pat. No. 4,559,157) and Wortzman (U.S. Pat. No. 4,820,508).

Useful dosages of the compounds of the present invention can be determined by comparing their *in vitro* activity, and *in vivo* activity in animal models. Methods for the extrapolation of effective dosages in mice, and other animals, to humans are known to the art; for example, see U.S. Pat. No.

5 4,938,949.

Generally, the concentration of the compound(s) of the present invention in a liquid composition, such as a lotion, will be from about 0.1-25 wt-%, preferably from about 0.5-10 wt-%. The concentration in a semi-solid or solid composition such as a gel or a powder will be about 0.1-5 wt-%, preferably
10 about 0.5-2.5 wt-%.

The amount of the compound, or an active salt or derivative thereof, required for use in treatment will vary not only with the particular salt selected but also with the route of administration, the nature of the condition being treated and the age and condition of the patient and will be ultimately at the
15 discretion of the attendant physician or clinician.

In general, however, a suitable dose will be in the range of from about 0.5 to about 10 ug/kg, e.g., from about 0.5 to about 10 ug/kg of body weight per day, such as 3 to about 5 ug per kilogram body weight of the recipient per day, preferably in the range of 6 to 90 ug/kg/day, most preferably in the range of 15
20 to 60 mg/kg/day.

The compound is conveniently administered in unit dosage form; for example, containing 10 to 50 ug, conveniently 15 to 50 ug, most conveniently, about 50 ug of active ingredient per unit dosage form.

Ideally, the active ingredient should be administered to achieve peak
25 plasma concentrations of the active compound of from about 0.5 to about 75 μ M, preferably, about 1 to 50 μ M, most preferably, about 2 to about 30 μ M. This may be achieved, for example, by the intravenous injection of a 0.05 to 5% solution of the active ingredient, optionally in saline, or orally administered as a bolus containing about 1-100 mg of the active ingredient. Desirable blood levels
30 may be maintained by continuous infusion to provide about 0.01-5.0 mg/kg/hr or by intermittent infusions containing about 0.4-15 mg/kg of the active ingredient(s).

The desired dose may conveniently be presented in a single dose or as divided doses administered at appropriate intervals, for example, as two, three, four or more sub-doses per day. The sub-dose itself may be further divided, *e.g.*, into a number of discrete loosely spaced administrations; such as multiple
 5 inhalations from an insufflator or by application of a plurality of drops into the eye.

VII. Assay Kits

The present invention also includes a diagnostic kit for detecting or
 10 determining the presence of a *Leptospira* infection. The diagnostic kit may also provide for the detection of the presence of LigA or LigB, or a combination thereof, in a physiological sample.

The kit comprises packaging, containing, separately packaged: (a) an amount of at least a first antibody which binds to a leptospiral protein or
 15 polypeptide; and (b) instruction means. Preferably, the antibody is labeled or is bound by a detectable label or a second antibody that is labeled.

The immobilized antibodies to LigA or LigB, and labeled antibodies to LigA and LigB, may be conveniently packaged in kit form, wherein two or more of the various immunoreagents will be separately packaged in preselected
 20 amounts, within the outer packaging of the kit, which may be a box, envelope, or the like. The packaging also preferably comprises instruction means, such as a printed insert, a label, a tag, a cassette tape and the like, instructing the user in the practice of the assay format.

For example, one such diagnostic kit for detecting or determining the
 25 presence of LigA or LigB comprises packaging containing, separately packaged: (a) a solid surface, such as a fibrous test strip, a multi-well microliter plate, a test tube, or beads, having bound thereto antibodies to LigA or LigB; and (b) a known amount of antibodies specific to LigA or LigB, wherein said antibodies comprise a detectable label, or a binding site for a detectable label.

30 The kit may comprise a mixture of antibodies, each of which binds to a different epitope on the same leptospiral protein or polypeptide, *e.g.*, a mixture of antibodies comprising antibodies that bind to SEQ ID NO:2 and antibodies that bind to SEQ ID NO:4, and/or SEQ ID NO:46.

The kit may also comprise a blocking agent, *e.g.*, BSA, which may be contacted with a sample to be tested before contacting the sample with the antibody, or may be contacted concurrently with the antibody. In one embodiment of the invention, the kit further comprises a known amount of a
 5 second antibody, which is detectably labeled or binds to a detectable label. The second antibody may bind to the same polypeptide as the first antibody, or may bind to the first antibody. Preferably, the kit is a diagnostic kit.

Also provided is a kit useful to detect a leptospiral protein or polypeptide in a sample. The kit comprises a solid substrate on which the sample to be tested
 10 is placed and a preparation of antibodies. Preferably, the antibodies are labeled or bind to a detectable label.

The invention will now be described by the following non-limiting examples.

15

Examples

Example I: Identification of LigA

Characterization of bacterial antigens expressed only during infection is essential in gaining a deeper understanding of infectious diseases such as
 20 leptospirosis. Immunoscreening of gene libraries with convalescent serum is a powerful tool in the discovery of these *in vivo* expressed immunogens, which would otherwise be difficult or impossible to identify. It has been previously shown that sera from horses that aborted as a result of naturally acquired *L. interrogans* serovar *pomona* type *kennewicki* infection recognize numerous
 25 periplasmic and outer membrane proteins, some of which are regulated by temperature (Nally, J. E. et al., *Infect. Immun.*, 69:400-404 (2001)). In this study, immunoscreening of a genomic library of *L. interrogans* serovar *pomona* type *kennewicki* was performed, and a novel, highly immunogenic protein expressed during equine infection (LigA) was identified.

30

Materials and Methods

Bacterial strains and culture conditions. *L. interrogans* serovar *pomona* type *kennewicki* was provided by Dr. M. Donahue (Diagnostic Laboratory, Department of Veterinary Science, University of Kentucky) who

isolated this strain from a case of ERU. Other serovars were obtained from the American Type Culture Collection (ATCC) and maintained in the Diagnostic Laboratory at Cornell University. Leptospire were grown on PLM-5 medium (Intergen, NJ) at 30°C. Growth was monitored by dark field microscopy.

- 5 Temperature regulation was carried out as previously described (Nally, J. E. et al., Infect. Immun., 69:400-404 (2001)).

Sera. Sera were obtained from mares that had recently aborted due to *Leptospira* infection. These sera had high titers for *L. interrogans* serovar pomona, as determined by the microscopic agglutination test. In most cases, the
10 diagnosis was confirmed by microscopic detection of leptospire in fetal tissues and the placenta. Rabbit anti-leptospiral antibody was obtained from NVSL, Iowa (1098-LEP-FAC). Antisera to LipL32 and LipL36 were kindly provided by D. A. Haake (UCLA, CA).

Genomic DNA library. Genomic DNA was prepared from *L.*
15 *interrogans* serovar pomona kennewicki as previously described (Chang, Y. F. et al., DNA Cell. Biol., 12:351-362 (1993)). Partial restriction digestion was performed with TSP5091 and the digested fragments were ligated into pre-digested lambda Zap II (Stratagene). Ligated DNA was packaged into Giga pack II Gold packaging extracts and stored in 0.3% chloroform. After
20 transfection into *E. coli* MRF' XL1 blue (Stratagene, CA), the library was plated, amplified, and screened with convalescent mare's serum according to the manufacturer's instructions (Stratagene, CA).

DNA sequencing and analysis. DNA sequencing was done using an ABI model 377 automated nucleic acid sequencer at the Bioresource Center,
25 Cornell University, NY. Homology searches were performed with NCBI, Blast (Altschul, S. F. et al., Nucleic Acid Res., 25:3389-3402 (1997)). Secondary structure, hydrophobicity and antigenic index predictions were obtained by using PCgene and DNA star.

Expression of *ligA* in *E. coli*.

30 *ligA* without the signal sequence (deletion of the N-terminal 31 amino acids) was amplified using primers (sense, 5'-GGGTTTCATATGGCTGGCAAAAGAGGC-3' (SEQ ID NO:35) and antisense, 5'-CCCTCGAGTGGCTCCGTTTAAAT-3' (SEQ ID NO:36)) and

subcloned into *NdeI-XhoI* sites of pET22b (Novagen, Madison, WI). The recombinant plasmid was transformed to *E. coli* BL21 (DE3) and expression was induced by IPTG as previously described (Chang, Y.-F. et al., Vet. Parasitol., 78:137-145 (1998)).

5 A 90 kDa truncated LigA was subcloned into the *XhoI-BamHI* sites of pET15b (Novagen) by PCR using primers (sense, 5'-
TCGAGGTCTCTCCAGTTTACC-3' (SEQ ID NO:37) and antisense, 5'-
GCGGATCCTGTTTTTCATGTTATGGCTCC-3')(SEQ ID NO:38). The
resulting plasmid was transformed into *E. coli* BL21 (DE3) and the truncated
10 recombinant LigA fusion protein was isolated from a lysate of BL21 by affinity chromatography on His Bind Resin (Novagen).

Preparation of LigA specific rabbit antiserum. Antiserum to a 90 kDa truncated LigA was prepared in adult New Zealand rabbits. Recombinant truncate was purified from periplasmic proteins of *E. coli* Nova blue that
15 contained pKS (Stratagene) encoding a 5kb *BamHI-SalI* fragment or by affinity chromatography on Avidgel F (UniSyn Technology Inc., Tustin, CA) to which IgG from convalescent mare's serum had been coupled. The rabbits were immunized subcutaneously with 50 µg of the 90 kDa truncated LigA mixed with complete Freund's adjuvant on day 1 followed by a booster inoculum of 50 µg
20 protein and incomplete Freund's adjuvant on days 10 and 19. On day 35, the rabbits were boosted intravenously with 50 µg of protein and then bled on day 45.

SDS PAGE and Immunoblot Analysis. Purified truncated LigA protein was subjected to SDS-PAGE and immunoblot analysis as previously
25 described (Chang, Y. F. et al., Infect. Immun., 63:3543-3549 (1995); Chang, Y. F. et al., DNA Cell. Biol., 12:351-362 (1993)). Rabbit antiserum to truncated LigA or convalescent mare's sera were used as primary antibodies. Blots were developed with peroxidase conjugated protein G or goat anti-horse IgG conjugated to alkaline phosphatase (KPL). Reactive bands were visualized by
30 using 4-1 chloro-naphthol (0.5 mg/ml) or nitroblue tetrazolium and 5 bromo-3-chloro indolyl phosphate as appropriate.

Immunohistochemistry. Immunohistochemistry was performed on normal and leptospiral infected hamster kidneys using biotin-streptavidin-

horseradish peroxidase according to the manufacturer's instructions (Zymed Laboratories, South San Francisco, CA). The chromagen was Nova Red (DAKO, Carpinteria, CA). The primary antibody was rabbit antiserum specific for truncated LigA and was titrated by using a two-fold serial dilution from 1:10 to 1:320. Negative controls consisted of non-immune rabbit serum diluted 1:10, 1:20 and 1:40. Anti-LipL32 was used as a positive control.

Kidneys were removed from leptospiral infected and normal hamsters euthanized as part of an unrelated research project. These tissues were immediately embedded in O.C.T. Compound (Miles, Elkhart, IN) and snap frozen in 2-methyl butane (Sigma, St. Louis, MO) prechilled to the point of freezing in liquid nitrogen.

Tissues were sectioned at 6 μ m, mounted on Microscope Plus slides (Fisher Scientific), fixed in acetone for 2 minutes and air-dried. Endogenous peroxidase was quenched for 10 minutes in 0.3% hydrogen peroxide in 0.1% w/v sodium azide and rinsed for 3 minutes in 0.01M phosphate buffered saline, pH 7.6 (PBS). Sections were then blocked with 10% heat inactivated goat serum for 10 minutes. The blocking serum was tipped off and the primary antibody applied for 60 minutes at room temperature. After rinsing 3 times in PBS, a 1:400 dilution of biotinylated goat anti-rabbit IgG was added for 20 minutes. Sections were rinsed 3 times and then incubated with a 1:400 dilution of the streptavidin-peroxidase reagent for 10 minutes. After rinsing, the chromogen-substrate mixture was added to the sections and the reaction monitored under the microscope until well developed or until background developed. The slides were again rinsed in PBS, counter-stained lightly with Gill's #1 hematoxylin (about 30 seconds), and then rinsed in tap water. Following dehydration in 2 changes of graded ethanol to 100% for 2 minutes each, the sections were cleared in 4 changes of 100% xylene for 2 minutes each and mounted with Fisher permount.

PCR amplification of *ligA* in pathogenic serovars. Using a primer pair specific for *ligA*, PCR was performed on pathogenic serovars including *L. interrogans* serovar pomona, type kennewicki, *L. kirschneri* serovar grippotyphosa, *L. interrogans* serovar hardjo, type hardjobovis, *L. interrogans* serovar icterohaemorrhagiae and *L. interrogans* serovar canicola. The forward

primer was “5'-GGAATTCATGTTAAAGTCACTGCT-3'” (SEQ ID NO:39) and the reverse was “5'-CCGCTCGAGGTTTAAATAGAGGC-3'”(SEQ ID NO:40). Amplification conditions were as previously described (Chang, Y.-F. et al., *Vet. Pathol.*, 37:68-76 (2000)). PCR products were purified using a gel-purification kit (Qiagen) and digested with *Bam*HI and *Hind*III to detect restriction polymorphisms.

Enzyme-linked immunosorbent assay (ELISA). Wells of 96 well polystyrene plates (Falcon 3912 Microtest III, Becton Dickinson, Oxnard, CA) were coated overnight at 4 °C with 0.15 µg truncated recombinant LigA in 100 µl PBS, washed, blocked with 2% skim milk in PBS (pH 7.2) with 0.05% Tween 20 and then incubated with a 1:100 dilution of horse serum in triplicate wells for 2 hours at 37°C. After washing, peroxidase conjugated protein G (1:8000) was added (100 µl) to each well and incubated for 2 hours at 37 °C. Finally, the plates were washed and developed with fresh substrate consisting of 0.07% orthophenylenediamine and 0.05% hydrogen-peroxide in citric acid-phosphate buffer (pH 5.0). After stopping the reaction with 50 µl 3M sulfuric acid, absorbance was read at 490 nm in an automated plate reader (Biotex, Winooski, VT).

Statistical analysis.

Analysis of variance was used to determine whether there was a significant difference in the mean OD reading for each of the sera used in this study. Multiple comparisons using the least significant difference method were performed to identify which OD mean was significantly different from the other. The analysis was performed using the Statistix software (Analytical Software, Tallahassee, FL).

Nucleotide sequence accession numbers. The GenBank accession number for the nucleotide sequences of *ligA* is AF368236.

Results

Identification, sequencing and expression of LigA. Screening of the *L. interrogans* genomic library with convalescent mare's serum yielded numerous positive clones, one of which contained an insert of 3,993 bp and expressed a protein that was encoded by an open reading frame of 3, 675 bp (Fig. 1). The

deduced sequence consisted of 1,225 amino acids with an estimated molecular mass of 129,041 daltons and a pI of 6.35. An N-terminal signal sequence of 31 amino acids was predicted using the Signal P program (Nielsen, H. et al., Protein Eng., 10:1-6 (1997)). Twelve or more tandem repeats of 90 amino acids were
 5 detected in LigA (Fig. 2). Analysis of the sequence using NCBI and BLAST revealed homology with the immunoglobulin-like domain of *E. coli* intimin (Genbank accession number AF252560), the putative invasin of *Yersinia pestis* (AJ41459) and the cell adhesion domain of *Clostridium acetobutylicum* (AE007823) (data not shown). LigA tandem repeats that showed homology with
 10 bacterial Ig-like domains (Igl1, CD:pfam02368; Igl2, CD: smart00635) are represented in Fig.2.

Expression of LigA in *E. coli* but not in *Leptospira* lysates. *E. coli* containing intact *ligA* without its signal sequence expressed LigA only after IPTG induction (Fig. 3), but LigA expression was toxic to *E. coli* resulting in a
 15 50 fold decrease in viability of cells (data not shown), which is similar to OmpL1 of *Leptospira* (Haake, D. A. et al., Infect. Immun., 67:6572-6582 (1999)). However, the expression of a 90 kDa truncated LigA was not toxic to *E. coli* cells (data not shown). Immunoblotting of whole cell lysates of *L. interrogans* serovar pomona type kennewicki grown at 30 and 37°C with LigA
 20 specific polyclonal rabbit serum did not show any detectable level of LigA (Fig. 4). In contrast, LipL32 was expressed by cultures grown at both 30 and 37°C whereas LipL36 was down regulated at 37°C.

LigA expression *in vivo* in *Leptospira*-infected hamsters. In order to examine LigA expression during leptospiral infection, immunohistochemistry
 25 was performed on kidneys from normal and leptospiral-infected hamsters. LigA was expressed only in leptospiral-infected hamster kidney (Fig. 5A). High titer rabbit anti-leptospiral serum as well as antiserum to LipL32 reacted with leptospires in experimentally infected kidney (Fig. 5B and 5C). LipL36, which is not expressed by *L. krischneri* serovar grippotyphosa in infected hamster
 30 kidney (Barnett, J. K. et al., Infect. Immun., 67:853-861 (1999)), was detected around the proximal convoluted tubules in *L. interrogans* serovar pomona infected hamster kidney at a 1:50 dilution of antiserum to LipL36 (Fig. 5D).

Pre-immune rabbit serum did not react (Fig. 5E) and no immune serum reacted with normal hamster kidney (data not shown).

LigA specific antibody in sera of convalescent mares and aborted fetuses. All convalescent sera showed strong reactivity with recombinant LigA by western blot analysis. Negative control horse sera derived from *Borrelia burgdorferi* (Chang, Y.-F. et al., Vet. Pathol., 37:68-76 (2000)), Human Granulocytic Ehrlichiosis agent (HGE) infection (Chang, Y.-F. et al., Vet. Parasitol., 78:137-145 (1998)) and naïve horse sera were unreactive (Fig. 6).

The utilization of LigA in ELISA also showed strong reactivity to the convalescent sera (Table 1 below). The mean OD for the leptospiral positive sera (M1-M8) was significantly different from the negative control (L1-L-5) and from sera obtained from HGE (E1-E2) and *B. burgdorferi* (N1-N4) infected animals ($P<0.05$).

Table 1

Serum	ELISA OD at serum dilution		
	1/200	1/400	1/800
Rabbit antiserum to a 90 kDa truncated LigA	1.13	1.02	.58
L1	.05	.03	.01
L2	.1	.04	.02
L3	.03	.02	.02
L4	.05	.02	.03
L5	.02	.01	.01
E1	.05	.03	.05
E2	.08	.05	.04
N1	.01	.01	0.0
N2	.01	.0	.0
N3	.02	.01	.01
N4	.03	.03	.01
M1	.39	.34	.19
M2	.38	.35	.18
M3	.45	.31	.2
M4	.6	.56	.27
M5	.28	.2	.13
M6	.47	.56	.4
M7	.73	.55	.4
M8	.56	.5	.42

Table 1. Reactivity in ELISA of rabbit antiserum to recombinant LigA, sera from horses infected with *B. burgdorferi* (L1-5) or *E. equi* (E1 and 2), normal horse sera (N1-4) and aborted mare's sera (M1-8) in ELISA with a 90 kDa truncated LigA (200 ng/well). The ELISA OD values of sera from aborted

mares were significantly higher ($P < 0.05$) than the values for sera from normal, *B. burgdorferi* and *E. equi* infected horses.

Detection of *ligA* in other serovars by PCR. PCR amplification

5 revealed the presence of *ligA* in genomic DNA of the pathogenic serovars hardjo, grippotyphosa, icterohaemorrhagiae and canicola (Fig. 7A). Restriction analysis with *Bam*HI revealed no differences in fragment patterns. However, *Hind*III digests revealed that *ligA* was more highly conserved in *L. interrogans* serovar pomona and *L. kirchneri* serovar grippotyphosa than in other serovars
10 (Fig. 7B).

Discussion

LigA is mostly hydrophilic with some hydrophobic regions located at residues 4-24, 306-326, 402-422, 490-510 and 1034-1054 (Fig. 1) and consists
15 of beta sheets with a few alpha helical regions. An Ala-Lys-Glu-Leu-Thr (SEQ ID NO:41) peptide repeat occurs at positions 416, 505, 594 and 867 corresponding to alpha helices. LigA contains 12 or more tandem repeats of a 90 amino acid sequence (Fig. 2). Analysis of the nucleotide sequences using NCBI and BLAST revealed no homology other than that between the repeat region of
20 LigA and the immunoglobulin-like domain of intimin binding protein (int) of *E. coli* (Hamburger, Z. A. et al., *Science*, 286:291-295 (1999); Kelly, G. et al., *Nat. Struct. Biol.*, 6:313-318 (1999); Luo, Y. et al., *Nature*, 405:1073-1077 (2000)), the invasin of *Yersinia pestis* (Isberg, R. R. et al., *Cell*, 50:769-778 (1999); Jerse, A. E. and J. B. Kaper, *Infect. Immun.*, 59:4302-4309 (1991)) and a cell binding
25 domain of *Clostridium acetobutylicum* (Nolling, J. et al., *J. Bacteriol.*, 183:4823-4838 (2001)).

Although sera from recently aborted mares reacted strongly with the 90 kDa truncated LigA, the protein was not detectable by immunoblot in *Leptospira* lysates cultured at 30° and 37°C. In contrast, LipL32 is expressed at both 30°
30 and 37°C while LipL36 expression is growth-phase dependant (Haake, D. A. et al., *Infect. Immun.*, 68:2276-2285 (2000); Nally, J. E. et al., *Infect. Immun.*, 69:400-404 (2001)). This indicates that LigA is not expressed or thermo-regulated under *in vitro* culture conditions.

However, immunohistochemistry using rabbit antiserum specific for a 90 kDa truncated LigA revealed expression of LigA in kidneys of infected but not uninfected hamsters. A commercially available high titer anti-leptospiral antiserum showed strong reactivity to the leptospiral organisms in infected hamster kidney. Expression of LipL32 was detected both *in vitro* (culture) and *in vivo* (leptospiral-infected hamster kidney) whereas LipL36 expression has been reported only *in vitro* (Barnett, J. K. et al., Infect. Immun., 67:853-861 (1999)). The *in vivo* expression of LipL32 has also been confirmed. However, the reactivity of LipL36 rabbit polyclonal antibody with infected hamster kidney at a 1:50 dilution was noted. In contrast, Barnett et al. failed to detect expression of LipL36 in *L. kirschneri* serovar grippotyphosa infected hamster kidney. These positive controls confirm that LigA is expressed only *in vivo*.

A 90 kDa protein of *Leptospira* has been previously shown to cross-react with polyclonal antiserum to an equine corneal protein (Lucchesi, P. M. and A. E. Parma, Vet. Immunol. Immunopathol., 71:173-179 (1999)). Immunohistochemistry, immunoprecipitation and Western blot analysis revealed no reactivity of LigA specific antiserum with equine cornea, iris, vitreous or lens (data not shown). Thus, LigA does not appear to share antigenic epitopes with equine ocular components and so it is clearly not the reactive protein (Lucchesi, P. M. and A. E. Parma, Vet. Immunol. Immunopathol., 71:173-179 (1999)).

PCR amplification of *ligA* from genomic DNA of pathogenic serovars such as hardjo, icterohaemorrhagiae, grippotyphosa, and canicola has shown that a similar sequence is widely distributed among the serovars of *L. interrogans*. However, restriction analysis with *HindIII* showed that the *ligA* sequence had greater similarity to that of serovars pomona and grippotyphosa than to serovars canicola and icterohaemorrhagiae. Interestingly, *L. interrogans* serovar pomona and *L. kirschneri* serovar grippotyphosa are the serovars most frequently responsible for disease in the horse.

The expression of outer membrane proteins of *Leptospira* such as LipL32, LipL41, OmpL1 and LipL36 has been demonstrated in cultured organisms (Haake, D. A. et al., J. Bacteriol., 175:4225-4234 (1993); Haake, D. A. et al., Infect. Immun., 68:2276-2285 (2000); Haake, D. A. et al., Infect. Immun., 66:1579-1587 (1998); Haake, D. A. et al., Infect. Immun., 67:6572-

6582 (1999)). Except for LipL36, these outer membrane proteins are expressed in infected hamsters. Interestingly, this is the first leptospiral protein that is not detectable *in vitro* (30 or 37°C) but is expressed in kidneys of infected hamsters.

5 Example II: Identification of LigB

ligB was obtained using the same procedures as were used to obtain *ligA*. To summarize, a genomic library of *L. interrogans* serovar Pomona type Kennewicki was constructed as previously described and was screened with convalescent sera from leptospiral infected horses and mares that aborted due to
10 leptospirosis (Palaniappan, R. U. M. et al., Infect. Immun., accepted (2002)). Several positive clones were identified and one of the recombinant clones contained an open reading frame (ORF) of 4200 bp (Fig. 8). The deduced sequence contained 1,420 amino acids with an estimated molecular weight of 140 kDa (SEQ ID NO:4). An N-terminal signal sequence of 31 aa was predicted
15 using the Signal P program (Nielsen, H. et al., Protein Eng., 10:1-6 (1997)). Three possible start codons for this protein were identified and upstream of the start codon of *ligB* is a potential ribosome-binding site (Fig. 8). NCBI Blast search revealed homology with the conserved bacterial immunoglobulin-like domain (Pfam Big 2) of intimins from *E. coli* (AF319597, AF301015,
20 AF116899) and cell adhesion domain from *C. acetobutylicum* (NC_003030).
Nucleotide sequence accession numbers. The GenBank accession number for the nucleotide sequences of *ligB* is AF534640.

Example III: Comparison of LigA and LigB

25 LigB has complete homology with LigA in the N-terminal sequences (up to 630 amino acids) but is variable in the carboxyl terminal. The structural analysis reveals that LigA and LigB are present on the surface of *Leptospira*. Interestingly, LigB contains twelve 90 amino acid sequence repeats whereas LigA consists of thirteen repeats. In addition, LigB contains an agglutinin-like
30 domain (lectin type) from residues 1054-1160, and a possible tyrosine kinase phosphorylation site from residues 1150-1158 (KEALDSLNY; SEQ ID NO:42). The comparison of intimin binding domain of translocated intimin receptor (Tir)

(272-304 residues) to LigB using Cn3D, NCBI revealed 25% homology to LigB (1353-1378 residues).

LigA and LigB are similar to intimin with a homology of 24%. Intimin has a Lys motif, two Ig-like domains, D1 and D2 (residues 658-751 & 752-841),
 5 and a C-type lectin-like domain D3 (residues 752-841). Similarly, Invasin has four Ig-like domains (D1-D4) and a C-type lectin-like domain (D5) (Bjorkman et al., 1999) whereas LigA and LigB consists of thirteen (D1-13) and twelve repeats (D1-D12) of 90 amino acids motif respectively which have homology to the bacterial domains with Ig-like fold (pfam Big2). Additionally, LigB
 10 contained a C-type lectin-like domain, D13 (residues 1014-1165) (Fig. 9). Recently, BipA from *Bordetella bronchiseptica* has been reported to contain 8 tandem repeats of 90 amino acids with a lectin-like carboxyl terminal (Stockbauer, K. E., et al., Mol. Microbiol., 39:67-78 (2001)). The intimin shares 24% homology with LigA and LigB respectively. Twelve repeats of LigB and
 15 its homology with bacterial Ig-like domain are depicted in Fig. 10.

Interestingly, LigB is identical in the N-terminal sequences (up to 630 amino acids) with LigA but varies in the carboxyl terminal (Fig. 11). The first 5 tandem repeats (residues 52-133, 137-222, 226-308, 312-398, 402-487 and 491-576) at the N-terminal regions of LigA and LigB are the same. Furthermore, a
 20 C-type lectin-like domain, especially the amino acids KEALDLSNY (SEQ ID NO:42; residues 1150-1158) contains tyrosine kinase phosphorylation sites according to the Scanprosite program (SWISSPROT). The alteration in the number of tandem repeats and variation in the carboxyl terminal of LigA and LigB may modify their antigenic determinants to evade the host immune
 25 response (Jones, C. J., West Indian Med. J. 23:65-68 (1974); Duncan, L. R. et al., Mol. Biochem. Parasitol., 48:11-16 (1991)).

The induction of attachment-effacing lesions by bacteria involves a three-stage model including initial attachment of bacteria to host cells, signal transduction and phosphorylation of host cells, and finally, intimate attachment
 30 of bacteria to the host cell membrane. *Yersinia* and *E. coli* mediate internalization into host cells using surface proteins such as invasin and intimin (Isberg, R. R. et al., Cell, 50:769-778 (1987); Jerse, A. E. et al., Proc. Natl. Acad. Sci. U.S.A., 87:7839-7843 (1990)). Invasin mediates entry by binding to

integrins that activate reorganization of the cytoskeleton (Tran Van Nhieu, G. and Isberg, R. R., Embo J., 12:1887-1895 (1993)). In Enteropathogenic *E. coli* (EPEC), intimin binds to Tir (translocated intimin receptor) produced by this bacterium, which eventually induces cytoskeletal rearrangements (Kenny, B. et al., Cell, 91:511-520 (1997)). Although the role of tyrosine phosphorylation in pedestal formation is unclear, Tir is tyrosin phosphorylated in EPEC but not in Enterohemorrhagic *E. coli* (EHEC) (DeVinney, R. et al., Cell Mol. Life Sci., 55:961-976 (1999)). It has been indicated that synthesis and secretion may be differentially regulated in these pathogens (DeVinney, R. et al., Cell Mol. Life Sci., 55:961-976 (1999)). These proteins are encoded by the genes in pathogenicity island, also called as locus of enterocyte effacement (LEE) (McDaniel, T. K. et al., Proc. Natl. Acad. Sci. U.S.A., 92:1664-1668 (1995)). LigB also contained a potential tyrosine kinase phosphorylation site but the localization of the gene in the pathogenicity island has not yet been unraveled. NCBI, Cn3D analysis revealed 25% homology to intimin binding region of translocated intimin receptor at the carboxyl terminal (residues 272-304) especially 32 amino acids with C-type lectin like domain of LigB. Since LigB contains an agglutinin- (lectin type) like domain with a possible tyrosine phosphorylation site at the carboxyl terminal and Tir like receptor, it seems that LigB may trigger cellular signaling events in the host cell.

The hydrophobicity of the deduced amino acid sequence and their potential membrane-spanning region was analyzed. Lig A and B are mostly hydrophilic with some hydrophobic regions and they consist of beta sheets with a few alpha helical regions. The predicted transmembrane region of LigB is from 300-319 residues (IIGSVKLIVTPAALVSI) (SEQ ID NO:43). Cysteine reportedly plays an important role in integrin binding and protein folding (Leong, J. M. et al., J. Biol. Chem., 268:20524-20532 (1993)); Frankel, G. et al., J. Biol. Chem., 271:20359-20364 (1996)). Invasin (Cys906 and Cys982) and intimin (Cys860 and Cys937) contain 2 cysteines and mutants lacking cysteine fail to interact with eukaryotic cells. Analysis of amino acids in the carboxyl terminal of Lig A and B revealed two molecules of cysteine in LigA whereas LigB contains eight cysteines. The numbers of serine and threonine residues in LigB are 224 and 147 whereas LigA has 179 and 142. Regardless, they are the

most dominant amino acids in both of these proteins. Similar to invasin and intimin, LigB lacks an Arg-Gly-Asp sequence (RGD), which is critical for the interaction of fibronectin Fn-III 10 with integrins (Hynes, R. O., Cell, 69:11-25 (1992)). However, Asp911 of invasin is critical for integrin binding (Hamburger, Z. A. et al., Science, 286:291-295 (1999)). A WIGL (trp-ile-glu-leu; SEQ ID NO:44) sequence, characteristic for calcium-coordinating residues that are critical for carbohydrate recognition, is not present in intimin, invasin (Hamburger, Z. A. et al., Science, 286:291-295 (1999)) and is also missing from LigB.

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Example IV: Expression of leptospiral immunoglobulin-like protein from *Leptospira interrogans* and evaluation of its diagnostic potential in Kinetic Enzyme Linked Immunosorbent Assay

15 Summary

The search for vaccine/diagnostic antigens against leptospirosis led to the identification of LigA (Palaniappan et al., Infect. Immun., 70:5924-5930, 2002). Similar to *ligA*, the *ligB* gene was obtained by screening a genomic library of *L. interrogans* with convalescent sera. The *ligB* gene contains an open reading frame of 5,667 bases that encodes 1,889 amino acids. LigB has complete homology with LigA at the amino terminal region, but is variable at the carboxyl terminal. LigB contains twelve, 90 amino acid sequence repeats of an immunoglobulin-like fold and an agglutinin-like domain (lectin type). Structural analysis revealed that LigA and LigB are surface proteins. Lig genes were present in most of the pathogenic serovars of *Leptospira*, but not in the non-pathogenic *L. biflexa*. LigA and LigB expression were not detectable at the translational level, but were detectable at the transcriptional level in *in vitro* grown leptospires. The conserved region and variable regions of LigA and LigB (Con, VarA and VarB) were cloned and expressed as GST fusion proteins. Kinetics-ELISA (KELA) was performed with GST fusion proteins of Con, VarA and VarB. Ninety-four canine sera positive for leptospirosis by MAT were evaluated in KELA with Con, VarA and VarB. Out of ninety-four, fifty-six MAT positive canine sera were found to be reactive in KELA. The conserved

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region of LigA and LigB showed stronger reactivity in KELA than variable regions of LigA and LigB. Canine sera with a MAT titer of >1,600 showed reactivity of 76% to Con, 41% to VarA and 35% to VarB respectively in KELA, suggesting the suitability of these antigens for the serological diagnosis of leptospirosis.

Leptospirosis is caused by spirochetes belonging to the genus *Leptospira*. considered the most widespread zoonotic disease in the world (World Health Organization, 1999). Leptospirosis affects both humans and animals (Vinetz, Curr. Opin. Infect. Dis., 14:527-38 (2001)). Infection is mainly contracted by exposure to water, food or soil contaminated with the urine from infected animals (Levett, Clin. Microbiol. Rev., 14:296-326 (2001)). Potential carriers of *Leptospira* include rats, cattle, dogs, horses, and pigs (Goldstein and Charon, 1990). Leptospirosis in dogs is recognized as a risk factor for human leptospirosis (Douglin et al., 1997). Increased rainfall is associated with a rise in the prevalence of leptospirosis in dogs (Ward, Prev. Vet. Med., 56:215-26 (2002)). Infection can lead to pulmonary hemorrhage, renal, hepatic failure and/or multi-organ failure and even death (Levett, Clin. Microbiol. Rev., 14:296-326 (2001)). An infected dog can also act as an asymptomatic carrier and shed infectious organisms in the urine for its entire lifetime (Murray, Vet. Rec., 127:543-7 (1990)). Approximately 250 serovars have been identified. The available leptospiral vaccines, however, elicit only short-term immunity and do not provide cross protection against different serovars.

Diagnosis of leptospirosis is complicated by the high degree of cross-reaction between different serovars of *Leptospira*. Furthermore, the non-pathogenic *L. biflexa* serovar Patoc, considered an environmental contaminant, provides a cross-reactive pattern to rabbit sera from pathogenic serovars of *Leptospira* (Matsuo et al., Microbiol. Immunol., 44:887-90 (2000); Myers, J. Clin. Microbiol., 3:548-55 (1976); Myers and Coltorti, J. Clin. Microbiol., 8:580-90 (1978)). Currently available diagnostic techniques include the microscopic agglutination test (MAT), which is laborious and not widely available. In addition, ELISA methods have been developed with number of modifications (da Silva et al., Am. J. Trop. Med. Hyg., 56:650-5 (1997); Gussenhoven et al., J. Clin. Microbiol., 35:92-7 (1997); Hartman et al., Vet.

Immunol. Immunopathol., 7:43-51 (1984); Hartman et al., Vet. Immunol. Immunopathol., 7:33-42 (1984); Levett, Clin. Microbiol. Rev., 14:296-326 (2001); Petchclai et al., Am. J. Trop. Med. Hyg., 45:672-5 (1991); Ribeiro et al., J. Trop. Med. Hyg., 98:452-6 (1995)), but most of them depend on the whole

5 cell proteins of *Leptospira*. Recombinant antigens such as LipL32, flagellin and heat shock protein of *Leptospira* have also been recently developed for diagnosis (Flannery et al., J. Clin. Microbiol., 39:3303-10 (2001); Park et al., DNA Cell Biol., 18:903-10 (1999)), but the specificity and sensitivity of these antigens in

10 vaccinated animals have not been determined. The major drawback with the MAT and ELISA procedures is that they cannot differentiate between infected and vaccinated animals. Identification of leptospiral antigens expressed only during infection could be used for the development of new diagnostic reagents that differentiate between vaccinated and infected animals.

In order to identify antigens that are expressed during leptospiral

15 infection, a genomic library of *L. interrogans* was screened with sera from infected animals. Several positive clones were obtained. One clone encoded a gene for a leptospiral immunoglobulin like proteins, referred to as LigA, that is only expressed *in vivo* (Palaniappan et al., Infect. Immun., 70:5924-30 (2002)).

The present application discloses the identification of another leptospiral

20 immunoglobulin-like protein, named LigB. LigB is identical to LigA at the amino terminus, but is variable at the carboxyl terminus. Truncated forms of the conserved region (Con) and variable regions of LigA (VarA) and LigB (VarB) were expressed as GST fusion proteins in *E. coli*. These recombinant antigens were used in a computer controlled kinetics-based enzyme linked

25 immunosorbent assay (KELA) and were evaluated for their diagnostic potential in vaccinated and MAT positive canine sera. Data disclosed herein indicate that these recombinant antigens can serve as diagnostic reagents for the detection of leptospiral infection.

30 Materials and Methods

Sera. Convalescent sera obtained from mares that had recently aborted due to leptospiral infection were used to a screen genomic library of *L.*

interrogans. These sera have high titers for *L. interrogans* serovar Pomona as determined by the microscopic agglutination test.

A total of 94 canine sera positive for leptospirosis by MAT (MAT positive canine sera) were collected from 1999 to 2002 from the New York State
5 Animal Health Diagnostic Laboratory at Cornell University, Ithaca, NY.

Vaccinated sera were obtained from eight week old puppies that had been vaccinated with commercially available vaccines, such as Grippotyphosa /Pomona (G/P), Canicola/Icteroheamorrhagiae (C/IC) and Grippotyphosa, Pomona, Canicola and Icterohaemorrhagiae (GPIC) followed by booster injection
10 three weeks later. Sera were collected before vaccination and on the 5th and 9th week after vaccination.

Control sera were obtained from dogs naturally infected with *Leishmania donovoni*, *Borrelia burgdorferi* or *Trypanosoma cruzi* and stored at New York State Diagnostic laboratory at Cornell University, Ithaca, NY.

15 Sera were also collected from specific pathogen free beagles (SPF) and also lyme-vaccinated dogs (Chang et al., *Infect. Immun.*, 63:3543-3549 (1995); Chang et al., *Am. J. Vet. Res.*, 62:1104-1112 (2001)).

Bacterial strains and culture conditions. *L. interrogans* serovar Pomona type kennewicki was isolated from an equine abortion (Wen et al.,
20 *Nature*, 422:888-893 (2003)). Leptospire were maintained on PLM-5 medium (Intergen, NJ), at 30°C. To isolate low passage cultures of leptospire, experimentally infected hamster tissues were homogenized and inoculated into PLM-5 medium. High passage cultures were prepared by repeated passage (<15 times) of leptospire in PLM-5 medium. Growth was monitored by dark field
25 microscopy.

DNA sequencing and analysis. The positive clones containing ligB gene (derived from screening a genomic library, as previously described) were subjected to DNA sequencing (Palaniappan et al., *Infect. Immun.*, 70:5924-5930 (2002)). DNA sequencing was done using an ABI model 377 automated nucleic
30 acid sequencer at the Bioresource Center, Cornell University, Ithaca, NY. Homology searches were performed with NCBI, Blast (Altschul et al., *Nucleic Acids Res.*, 25:3389-3402 (1997)).

Construction of GST fusion proteins of Lig A and LigB. LigA and LigB were truncated into conserved (Con, the N-terminal 599 amino acids without the signal sequences) and variable regions (VarA and VarB, the C-terminal 595 and 788 amino acids of LigA and LigB, respectively). The regions were amplified using PCR with the following primers ligConF. 5'-
 5]"TCCCCCGGGGCTGGCAAAAGA," (SEQ ID NO:47) ligConR. 5'-
 "CCCTCGAGAATATCCGTATTAGA," (SEQ ID NO:48) VariAF, 5'-
 "CCCCCGGGGCTTACCGTTCC," (SEQ ID NO:49) VariAR, 5'-
 "CCCTCGAGTGGCTCCGTTTTAAT," (SEQ ID NO:36) VariBF, 5'-
 10 "TCCCCCGGGGCTGAAATTACAAAT," (SEQ ID NO:50) VariBR, 5'-
 "CCGCTCGAGT TGGTTTCCTTTTACGTT" (SEQ ID NO:51). The underline nucleotides indicate the restriction site. PCR was performed using 0.5 units accuprime Taq polymerase (Invitrogen, CA). Other reagents were added as outlined by the manufacturer's instructions (Invitrogen, CA). The reaction
 15 mixture was subjected to 35 cycles after an initial denaturation at 94°C for 5 minutes. Each cycle consisted of 94°C for 1 minute, 50°C for 2 minutes and 72°C for 5 minutes.

PCR products were subcloned using a TOPO TA cloning kit (Invitrogen, Carlsbad, CA) into pGEX4T-2 plasmids (Amersham Pharmacia). The
 20 recombinant plasmids (pLigCon, pLigVarA, pLigVarB) were then introduced into *E. coli* BL21 (DE3). The resulting transformants were grown at 37°C overnight on LB agar plates containing 50 µg/mL ampicillin. The expression of proteins was induced with 1mM IPTG.

Purification of GST fusion proteins. IPTG induced *E. coli* BL21 (DE3)
 25 containing the recombinant plasmids was harvested by centrifugation at 5000 rpm. The cell pellets were washed and suspended in PBS followed by passing through a French pressure cell (American Instrument, Silver Spring, MD). The lysates were then centrifuged to remove the cell debris, and the supernatants were subjected to affinity chromatography using glutathione-Sepharose 4B
 30 columns. (Amersham Pharmacia Biotech, Piscataway, NJ). The GST fusion proteins were eluted according to the manufacturer's instructions (Amersham Pharmacia Biotech, Piscataway, NJ).

Generation of Polyclonal Antibodies. Adult New Zealand white rabbits were immunized intramuscularly with 100 µg of GST fusion proteins and an equal amount of Freund's incomplete adjuvant. Rabbits were boosted subcutaneously with the same dosage on the 19th and 35th day. On day 45, the rabbits were bled, and the sera were collected for analysis.

SDS-PAGE and Immunoblot analysis. The recombinant proteins were subjected to sodium dodecyl sulfate-polyacrylamide gel electrophoresis followed by immunoblot as previously described (Chang et al., *Infect. Immun.*, 63:3343-9 (1995); Chang et al., *Am. J. Vet. Res.*, 62:1104-12 (2001); Chang et al., *DNA Cell Biol.*, 12:351-62 (1993)).

RT-PCR. RNA was isolated from log phase cultures of leptospire using an RNA mini kit (Qiagen Inc.), treated with RNAase free DNAase, and subjected to one step RT-PCR with gene specific primers (variable region of *ligA* and *B*). The following primers were used for RT-PCR: VariAF, 5'-GAAAATCGCATCAGTAGAAAAC (SEQ ID NO:52); VariAR, 5'-CCCTCGAGTGGCTCCGTTT TAAT (SEQ ID NO:36), VariBF, 5'-TAAACAAAACGGACACGATAGC (SEQ ID NO:53); VariBR, 5'-CCGCTCGAGTTGGTTTCTTTTACGTT (SEQ ID NO:51). The reactions were carried out according to the manufacturer's instructions (Qiagen). A reaction containing all the reagents except for reverse transcriptase was used as a negative control. Genomic DNA was used as a positive control.

Southern blot analysis. Genomic DNA isolated from leptospiral strains was digested with *EcoRI* and subjected to gel electrophoresis. DNA was transferred to Hybond N+ nitrocellulose membranes (Amersham Pharmacia). The membranes were processed as outlined in the manufacturer's instructions for ECL direct nuclei labeling and detection system (Amersham Pharmacia, NJ). The conserved region of the *lig* gene was used as the probe for the Southern blot analysis.

Optimization of antigen concentration. Based on MAT titer, canine sera were categorized into high (MAT titer of 12,800 to Pomona, 6,400 to Grippotyphosa), low (MAT titer of 6,400 to Pomona, 3,200 to Grippotyphosa) and negative (SPF, specific pathogen free serum). A checkerboard titration of recombinant antigens (Con, VarA and VarB), primary antibodies (negative,

medium and high) and secondary conjugate (anti-dog conjugated with horseradish peroxidase) was performed to determine the optimum conditions.

Kinetic ELISA (KELA). The optimized concentrations of recombinant antigens were diluted in 0.1M bicarbonate buffer and added to a 96 well microtiter plate (Nunc, Denmark). The plates were rocked for 1 hour and then incubated overnight at 4°C. The plates were washed three times with 0.1M PBS containing 0.05% Tween 20 (PBST). Canine sera (primary antibody) in PBST were diluted to 1: 200. 100 µl of diluted serum was added to each well and the plates were incubated for 1 hour at 37°C in a humid chamber. The plates were washed three times with PBST, and then incubated with 100 µl of a 1: 4000 dilution of goat anti-dog IgG conjugated to horseradish peroxidase (Cappel, Durham, NC) for 30 minutes at room temperature. The plates were washed again three times with PBST, and 100 µl of TMB (Kirkegaard, MD) was added to each well. Each plate was read three times in a microplate spectrophotometer (Bio-Tek EL-312, Winooski, VT) at 650nm OD with an interval of 1-minute. The results were calculated by the KELA computer program (Diagnostic Laboratory, College of Veterinary Medicine, Cornell University) and expressed as the slope of the reaction between enzyme and substrate to the amount of antibody bound (Chang et al., Infect. Immun., 63:3543-3549 (1995); Chang et al., DNA Cell Biol., 12:351-362 (1993)).

Statistical analysis. The significance of differences between the recombinant proteins in relation to KELA units was evaluated using the analysis of variance statistical method. The analysis was performed in STATISTIX (Analytical software, Tallahassee, FL). The least square difference post-hoc test was used to determine mean KELA value and the significant difference of the recombinant proteins. The correlation between MAT and KELA for the six serovars of *Leptospira* was evaluated using the Pearsons Correlation in STATISTIX. This correlation was assessed for each recombinant protein separately. Descriptive statistics were performed to determine the cut off value for each protein in relation to KELA.

Nucleotide Sequence Accession Number. The Genbank accession number for the nucleotide sequence of *ligB* is AF534640.

Results

Identification, sequencing and expression of LigB. A leptospiral genomic library was constructed as previously described. The library was screened with convalescent sera obtained from leptospiral-infected mares that had aborted (Palaniappan et al., *Infect. Immun.*, 70:5924-5930 (2002)). Several positive clones were identified, one of which contained an open reading frame (ORF) of 5,667 bp. The deduced protein sequence contained 1,889 amino acids and had an estimated molecular weight of 206 kDa. An N-terminal signal sequence of 31 amino acids was predicted using the signal P program (Nielsen et al., *Protein Eng.*, 10:1-6 (1997), Nielsen et al., *J. Am. Vet. Med. Assoc.*, 199:351-352 (1991)). Three possible start codons for this protein were identified and upstream of the start codon of *ligB* is a potential ribosome-binding site. The recently released genomic sequences of *L. icterohaemorrhagiae* serovar lai contained LigB but not LigA (Genbank number AA065920), which shows 98% homology with LigB of *L. interrogans* serovar Pomona (Ren et al., *Nature*, 422:888-893 (2003). NCBI Blast search revealed homology with the conserved bacterial immunoglobulin-like domain (Pfam Big 2) of intimins from *E. coli* (AF319597, AF301015, AF116899) and cell adhesion domain from *Clostridium acetobutylicum* (NC-003030).

Primary structure of LigB and comparison with LigA. LigB consists of twelve repeats (D1-D12) of a 90 amino acid motif, which has homology to the bacterial domains with Ig-like fold (pfam Big2) (Fig. 13A). It has been reported that LigA contains twelve repeats of a 90 amino acid motif, but according to pfam, LigA actually has thirteen repeats of the 90 amino acid motif. Additionally, LigB contains a C-type lectin-like domain, D13 (residues 1014-1165).

The amino terminal sequence (the first 630 amino acids) of LigB is identical to LigA, but the carboxyl terminus varies (Fig 13B). The first 5 tandem repeats (residues 52-133, 137-222, 226-308, 312-398, 402-487 and 491-576) at the N-terminal regions of LigA and LigB are identical. Furthermore, a C-type lectin-like domain, especially the amino acids KEALDLSNY (residues 1150-1158), contains tyrosine kinase phosphorylation sites according to the Scanprosite program (SWISSPROT). The numbers of serine and threonine

residues in LigB are 224 and 147, whereas LigA has 179 and 142, respectively. Regardless, serine and threonine are the most dominant amino acids in both of these proteins.

The hydrophobicity of the deduced amino acid sequence and the potential membrane-spanning region of LigA and B was analyzed. These two proteins are largely hydrophilic with some hydrophobic patches, and they consist of beta sheets with a few alpha helical regions. The predicted transmembrane region of LigB spans residues 300-319 (IIGSVKLIVTPAALVSI) (SEQ ID NO:43).

***lig* genes are widely spread, but only in pathogenic serovars.** In order to determine the presence of *lig* genes in different serovars of *Leptospira*, *EcoRI* digested genomic DNA from different serovars of *Leptospira* was transferred to nitrocellulose membranes, and probed with a non-radioactively labeled oligonucleotide from the conserved regions of LigA and LigB. Non-pathogenic *L. biflexa* serovar Patoc did not contain *lig* genes, but the other pathogenic serovars contained copies of *lig* genes (Fig. 14).

Expression and purification of LigA and B. In order to over express LigA and B, the truncated forms of the conserved and variable regions of LigA and B were cloned and expressed as GST fusion proteins. The expressed recombinant proteins of the conserved and variable regions of LigA and LigB had molecular weights of 92, 93, and 120 kDa, respectively. GST fusion proteins were purified using affinity column chromatography and thrombin cleaved proteins migrated as 62, 63, and 82 kDa, respectively (Fig. 15A, B and C).

Lack of LigA and LigB expression at the translation level in leptospire. To examine LigA and B expression in leptospire, immunoblots of whole cell proteins of low and high passage cultures of leptospire were probed with polyclonal antibodies to Con, VarA and VarB. LigA and LigB expression was not detectable in leptospire grown *in vitro* (Fig. 16A, B and C). In contrast, *E. coli* containing the recombinant plasmids showed strong reactivity. The negative control, *E. coli* without the insert in the vector, showed no reactivity.

Detection of LigA and B at the transcript level in leptospire grown *in vitro*. RT-PCR with RNA of low passage and high passage cultures detected

the expression of LigA and LigB at the transcript level (Fig. 17). Genomic DNA of leptospire was used as a positive control. The negative control, which lacked reverse transcriptase did not show any amplification. This indicates that LigA and LigB may be poorly expressed under *in vitro* conditions or the proteins are very unstable.

Optimization of recombinant antigen concentrations. LigA and LigB were truncated into the conserved region of LigA and LigB, variable region of LigA and variable region of LigB and expressed as GST fusion proteins. A checkerboard titration technique was used to determine the optimal concentrations of reagents for ELISA. Based on this, 1µg of recombinant antigen was chosen and the dilution rate of primary and secondary conjugated antibodies were assessed as 1:200 and 1:4,000, respectively. Since these recombinant antigens were expressed as GST fusion proteins, GST was used as control and the reactivity rate of GST was subtracted for the analysis of samples.

Determination of cut off value: A total of 20 sera collected from unvaccinated/healthy dogs were analyzed in KELA with GST, Con, VarA and VarB. The KELA value for the reactivity of unvaccinated sera to the recombinant antigens was obtained by subtracting the reactivity of GST. The cut off value was determined from the unvaccinated dogs using descriptive statistical analysis (Table 1). All the sera showed negative KELA value in KELA with the recombinant antigens except two sera. The maximum KELA unit of sera from unvaccinated/healthy dogs was considered as the cut off value. The cut off KELA value of Con, VarA and VarB were 7, 42, and 42, respectively.

Table 1. Descriptive statistics of KELA value (KELA) to the recombinant antigens in unvaccinated/healthy dogs

		Con	VarA	VarB
1	Lower limit 95% CI	0	-1.8578	0
2	Upper limit 95% CI	2.0188	10.328	5.525
3	Mean	0.8235	4.2353	2.5294
4	Standard deviation	2.3247	11.8531	8.5855

5	Maximum	7	42	42
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Lack of antibodies in the vaccinated sera to recombinant antigens of LigA and LigB. A serial bleed from dogs vaccinated with commercially available vaccines showed MAT titer of less than 400 (Table 2).

5

Table 2. MAT titer value for the sera from vaccinated dogs

Dogs	MAT titer to Pomona for vaccinated sera			MAT titer to Grippytyphosa for vaccinated sera		
	5.5 wks	7 wks	10 wks	5.5 wks	7 wks	10 wks
G/P	---	---	---	---	---	---
C/IC	---	---	---	---	---	---
GPIC	---	---	---	---	---	---
G/P	200	200	---	---	---	---
GPIC	---	---	---	---	---	---
G/P	100	400	---	---	---	100
C/IC	---	---	---	---	---	---

10 G/P represents dogs vaccinated with Grippytyphosa and Pomona vaccine; GPIC denotes dogs vaccinated with Pomona, Grippytyphosa, Icterohaemorrhagiae and Canicola; C/IC represents dogs vaccinated with Canicola and Icterohaemorrhagiae (C/IC)

15 Analysis of these vaccinated sera showed no reactivity to recombinant antigens Con, VarA and VarB in KELA but showed reactivity to the whole cell proteins of *Leptospira interrogans* in the western blot analysis (Fig. 18) and in ELISA (our unpublished data). In the western blot analysis with whole cell lysates, most of the vaccinated sera from dogs showed reactivity with leptospiral antigens. For example, Grippo/Pomona combined vaccinated sera reacted with whole cell antigens at 66, 50, and 42 kDa, whereas naturally infected sera from
20 dogs showed reactivity with leptospire antigens at 66, 42, 33, 32, 27 and 21 kDa (Fig. 18). The descriptive statistical analysis of KELA with sera from the vaccinated dogs was below the cut off value (Table 3).

Table 3. Descriptive statistics of KELA value (KELA) to the recombinant antigens in vaccinated dogs

		Con	VarA	VarB
1	Lower limit 95% CI	0.0809	0	0.1102
2	Upper limit 95% CI	1.5381	2.077	1.5088
3	Mean	0.8095	0.8095	0.8095
4	Standard deviation	1.6006	2.786	2.2441
5	Maximum	6	12	12

5 **Reactivity of MAT positive canine sera to recombinant antigens in KELA.** The diagnostic potential of recombinant antigens of LigA and LigB to detect leptospiral-infected dogs was assessed in KELA using MAT positive canine sera. A total of ninety-four MAT positive canine sera were categorized based on the MAT titer and the reactivity to KELA with recombinant antigens

10 Con, VarA and VarB was established based on the cut off value. Fig. 19A, B and C represent the reactivity of MAT positive canine sera with recombinant proteins Con, VarA and VarB. The recombinant antigen Con, VarA and VarB in KELA showed reactivity of 76%, 41% and 35%, respectively, to canine sera with MAT titer of more than 1,600, but the overall sensitivity of recombinant

15 antigens Con, VarA and VarB to MAT-positive canine sera was 58%, 30% and 17%, respectively (Table 4).

Table 4. Comparison of efficiency of recombinant antigens in KELA to MAT positive canine sera.

20

MAT titer	Reactivity of recombinant antigens in KELA		
	Con	VarA	VarB
12,800	88%	73%	58%
6,400	81%	27%	22%
3,200	67%	42%	8%
1,600	67%	22%	11%
800	28%	7%	0
400	15%	8%	0
Overall	58%	30%	17%

The sensitivity of recombinant antigens in KELA was determined from MAT positive canine sera, which did not have a case history for vaccination. Based on

the cut off value the percentage of reactivity of recombinant antigens to MAT titer value is represented.

The low titer (below 1,600) MAT-positive canine sera did not show reactivity to the recombinant antigens. Comparing the reactivity of these recombinant antigens with MAT positive canine sera, there are significant differences between Con, VarA and VarB in the KELA units. The mean KELA units for Con and VarA are not significantly different from each other. Post-hoc tests showed that VarB had significantly lower KELA units (19.4) in comparison to Con (53.6) and VarA (41.43). Dogs infected with leishmaniosis, trypanosomosis and borreliosis did not show reactivity to the recombinant antigens suggesting that there is no cross reactivity of these antigens with these agents.

Lack of Correlation between MAT positive and KELA. The correlation between MAT and KELA with recombinant antigens of LigA and LigB was studied but it showed poor correlation (Table 5).

Table 5. Correlation between MAT and KELA units in the clinical samples.

Recombinant proteins	Bratislava	Canicola	Grippotyphosa	Hardjo	Icterohaemorrhagiae	Pomona
Con	0.0107	-0.2491	0.281	0	0.525	0.2454
VarA	0.271	-0.2467	-0.0348	0	0.2021	0.3273
VarB	0.2863	-0.1308	-0.1741	0	0.1129	0.0125

There was poor correlation between MAT and KELA for six serovars of *Leptospira* using pearson correlation in statistix

Discussion

On first exposure to pathogenic bacteria, a host's immune system generates antibodies directed against cell surface or membrane antigens. Since the antibodies against cells surface antigens may abrogate colonization, recombinant antigens from cell surface or membrane proteins may serve as candidates for the development of novel vaccines and improved diagnostic tests. In this study, LigB was identified by immuno-screening of a genomic library of *L. interrogans* serovar Pomona. Its expression in *in vitro* grown leptospires was studied. The conserved and variable regions of LigA and LigB were expressed

as GST fusion proteins, and a KELA test was developed for the detection of leptospiral infection.

Previously, the lack of expression of LigA *in vitro* using high passage cultures of leptospires was demonstrated (Palaniappan et al., Infect. Immun., 70:5924-5930 (2002)). Similarly, LigB expression *in vitro* is not detectable in high and low passage cultures of leptospires. However, both LigA and B are detectable at the transcript level. The lack of detection of LigA and LigB in *in vitro* grown leptospires suggests that these proteins are either poorly expressed *in vitro*, or are unstable after expression. Recently, one copy of *lig* was expressed very weakly in low passage *L. kirschneri* RM52 (Matsunaga et al., International Conference on Leptospirosis, Barbados (2002). However, the expression of LigA or LigB at the translational level in low passage strain of *L. interrogans* was not detected herein. The re-establishment of LigA and LigB expression upon infection and the absence of these genes in non-pathogenic leptospires suggests that they are virulence factors of pathogenic leptospires.

The currently available whole cell leptospiral vaccines elicit a short-term immunity. Moreover, they are ineffective in cross protection against different serovars. Thus, vaccinated dogs may contract leptospirosis by the same or different serovars (Brown et al., J. Am. Vet. Med. Assoc., 209:1265-1267 (1996); Cole et al., J. Am. Vet. Med. Assoc., 180:435-437 (1982); Everard et al., Trop. Geogr. Med., 19:126-132 (1987); Harkin and Gargell, J. Am. Anim. Hosp. Assoc., 32:495-501 (1996)). Currently available serological tests are unable to discriminate between vaccine induced leptospiral antibodies and those due to infection. A high MAT titer indicates infection, but a high titer may also be achieved by subsequent vaccination (Goddard et al., Vet. Microbiol., 26:191-201 (1991)). Additionally, MAT is a reliable test for diagnosis, but it is mainly focused on major serovars such as Pomona, Grippotyphosa, Canicola, Icterohaemorrhagiae and Hardjo. Therefore, there is a need for a diagnostic reagent based on antigens that are expressed only during infection to identify animals that contract leptospirosis despite vaccination. Moreover, the cross-reactivity within various pathogenic serovars in the MAT needs to be validated.

Some of the MAT positive sera having a low MAT titer value of less than 200 to the above-mentioned serovars of *Leptospira* had high KELA values

in the KELA assay disclosed herein that uses recombinant antigens of LigA and LigB. Further analyses of these sera for other serovars such as Autmnalis and Bratislava showed high MAT titer value. The KELA disclosed herein having recombinant antigens from the conserved region of LigA and LigB thus can be
 5 utilized as a diagnostic tool for leptospirosis.

KELA with recombinant antigens to the conserved regions of LigA and LigB (Con) showed stronger reactivity than VarA and VarB to MAT positive canine sera (Table 4). The overall sensitivity of the recombinant antigens Con, VarA and VarB to MAT positive canine sera was 58%, 33% and 17%,
 10 respectively.

In conclusion, the KELA disclosed herein using recombinant LigA and LigB antigen is specific for the serodiagnosis of leptospiral infection. The lack of antibodies to the recombinant LigA and LigB antigens in vaccinated sera suggests that these antigens can be used to identify natural infection of
 15 leptospirosis despite vaccination.

Example V: Use of LigA protein as a vaccine candidate against
 infection by *L. interrogans* serovar *Pomona*

20 The cloning of LigA protein of *Leptospira interrogans* was previously reported. The potential use of this protein as a vaccine candidate against infection by *L. interroigans serovar Pomona* was evaluated herein. LigA was truncated into the N-terminal 599 amino acids conserved region (Con, without the signal sequence) and the C-terminal 595 amino acid variable region of LigA
 25 (VarA) and expressed in *Escherichia coli* as a fusion protein with glutathione-S-transferase (rCon-GST and rVarA-GST). Eight Golden Syrian hamsters were vaccinated with rCon-GST and rVarA-GST along with adjuvant aluminum hydroxide at 4 and 8 week of age. Sixteen hamsters were used as nonvaccinated controls with GST-adjuvant (8 animals) and adjuvant (8 animals). Three weeks
 30 after the last vaccination, all animals were intraperitoneally inoculated with 10⁸ of *L. interrogans serovar Pomona* (NVSL 1427-35-093002). All eight vaccinated hamsters survived after challenge. In contrast, 2 or 3 out of 8 animals died 2 weeks after challenge in the GST-adjuvant and adjuvant control group, respectively. Hamsters in the control groups had kidney lesions and were also

culture positive in various tissues, but not the vaccinated ones. RCon-GST/rVar-GST elicited an antibody response to rCon in the hamsters by kinetic enzyme-linked immunosorbent assay. Results from this study show that vaccination with rCon-GST/rVar-GST protected hamsters against infection and disease after
5 challenge with *L. interrogans* serovar *Pomona*.

While in the foregoing specification this
15 invention has been described in relation to certain preferred embodiments thereof, and many details have been set forth for purposes of illustration, it will be apparent to those skilled in the art that the invention is susceptible to additional embodiments and that certain of the details described herein may be varied considerably without departing from the basic principles of the invention.

20

Claims:

1. An isolated and purified polynucleotide, wherein the polynucleotide: (i) comprises a nucleic acid sequence encoding a LigB polypeptide from *Leptospira interrogans*, wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (ii) consists of SEQ ID NO: 45.
2. The polynucleotide of claim 1, wherein the polynucleotide comprises SEQ ID NO: 3 or consists of SEQ ID NO: 45.
3. An isolated and purified LigB polypeptide from *Leptospira interrogans*, wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of SEQ ID NO: 46.
4. The polypeptide of claim 3, wherein the polypeptide comprises SEQ ID NO: 4 or consists of SEQ ID NO: 46.
5. A pharmaceutical composition comprising:
 - (i) a purified LigB polypeptide from *Leptospira*, wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of SEQ ID NO: 46; and
 - (ii) a pharmaceutically acceptable carrier, wherein the composition is capable of eliciting an immune response against *Leptospira interrogans*.
6. The pharmaceutical composition of claim 5, further comprising an effective amount of an immunological adjuvant.
7. A vaccine comprising an immunogenic amount of a purified LigB polypeptide from *Leptospira* in combination with a physiologically acceptable, nontoxic vehicle; wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of SEQ ID NO: 46; and wherein the amount of LigB polypeptide is effective to immunize a mammal susceptible to *Leptospira* infection or colonization.

8. The vaccine of claim 7, further comprising an effective amount of an immunological adjuvant.
9. The vaccine of claim 7, wherein the mammal is a human, dog, bovine, porcine, or horse.
10. Use of the pharmaceutical composition of claim 5 for eliciting an immune response in a subject against *Leptospira interrogans*.
11. Use of the pharmaceutical composition of claim 5 for preventing *Leptospira interrogans* in a subject.
12. Use of an effective amount of a vaccine for protecting a susceptible mammal against *Leptospira* infection or colonization, the vaccine comprising an immunogenic amount of a purified LigB polypeptide from *Leptospira* in combination with a physiologically acceptable, nontoxic vehicle; wherein the LigB polypeptide (a) comprises the amino acid sequence of SEQ ID NO: 4, or (b) comprises the amino acid sequence of SEQ ID NO: 34, or (c) consists of SEQ ID NO: 46; and wherein the amount of LigB polypeptide is effective to immunize a mammal susceptible to *Leptospira* infection or colonization.
13. A composition comprising a pharmaceutically acceptable carrier and an amount of: (a) an immunologically active protein comprising SEQ ID NO: 4 or SEQ ID NO:34, or (b) an immunologically active polypeptide that consists of SEQ ID NO: 46, and which amount is effective to stimulate the formation of antibodies against *Leptospira interrogans* in a mammal.
14. A composition comprising a pharmaceutically acceptable carrier and an amount of: (a) an immunologically active protein comprising SEQ ID NO: 4 or SEQ ID NO:34, or (b) an immunologically active polypeptide that consists of SEQ ID NO: 46, and which amount is effective to immunize a susceptible mammal against infection caused by *Leptospira*.

15. The composition of claim 13, wherein the composition is effective to immunize a susceptible mammal against infection caused by *Leptospira*.
16. The composition of claim 13 or 14, which further comprises an effective amount of an immune stimulating agent.
17. Use of a composition comprising an effective amount of an immunologically active protein comprising SEQ ID NO: 4, comprising SEQ ID NO:34, or consisting of SEQ ID NO: 46 and at least one pharmaceutically acceptable excipient, for stimulating the formation of antibodies against *Leptospira*.
18. The use of claim 17, wherein the composition further comprises an effective amount of an immune stimulating agent.
19. The use of claim 17, wherein the composition is effective as a vaccine.
20. An assay kit for detecting antibodies against *Leptospira* strains, wherein the assay kit contains at least one immunologically active purified LigB protein derived from *Leptospira interrogans*, wherein such protein is characterized in that it:
 - a. elicits an immunological response from a mammal;
 - b. has been prepared by expression in a bacterium other than *Leptospira interrogans*;
 - c. is free of other *Leptospira interrogans* proteins; and
 - d. is a protein comprising SEQ ID NO: 4, comprising SEQ ID NO:34, or consisting of SEQ ID NO: 46, which protein reacts with the antibodies present in a test fluid, and wherein said kit has at least one indicator component which detects complexes of immunologically active protein and antibody.
21. The assay kit of claim 20, wherein the indicator component is an antibody which is directed against the antibody to be detected and which has a label.
22. The assay kit of claim 21, wherein the label comprises a radioactive isotope.
23. The assay kit of claim 21, wherein the label comprises an enzyme which is able to catalyze a color reaction.

24. The assay kit of claim 20, wherein the immunologically active protein is biotinylated, and the indicator component is avidin or streptavidin having an enzyme covalently bonded thereto.
25. The assay kit of claim 20, which is an ELISA assay kit.
26. The assay kit of claim 25, wherein the at least one immunologically active protein is coupled to microtiter plates, and the indicator component comprises anti-human immunoglobulin to which an enzyme catalyzing a color reaction is coupled.
27. The assay kit of claim 24 or 26, wherein the enzyme is peroxidase.
28. The assay kit of claim 26, wherein the indicator component comprises IgG antibodies, IgM antibodies, or a mixture thereof.
29. An antibody specific for the purified LigB polypeptide of claim 3.
30. The antibody of claim 29, wherein the antibody is a monoclonal or polyclonal antibody.
31. A method for the detection of *Leptospira* infection in a mammal, comprising the steps of:
 - (a) contacting LigB protein from *Leptospira interrogans* with a biological sample from a mammal suspected of having *Leptospira* infection, wherein the LigB protein is a protein comprising SEQ ID NO: 4, comprising SEQ ID NO:34, or consisting of SEQ ID NO: 46, and
 - (b) detecting the presence or absence of a complex formed between LigB and antibodies in the biological sample, thereby indicating pathogenic *Leptospira* infection in the mammal, wherein the presence of a complex formed between LigB protein and antibodies in the biological sample indicates *Leptospira* infection in the mammal.
32. The method of claim 31, wherein said detecting comprises: contacting the sample, after said contacting LigB protein from *Leptospira interrogans* with a biological sample, with an indicator component which detects complexes of immunologically active LigB protein and antibodies from the biological sample.
33. The method of claim 31, wherein the LigB protein comprises SEQ ID NO: 4.

34. The method of claim 31, wherein the LigB protein comprises SEQ ID NO:34.
35. The method of claim 31, wherein the LigB protein consists of SEQ ID NO: 46.
36. The use of claim 12, the composition of any one of claims 13 to 15, the assay kit of claim 20 or the method of claim 31, wherein the mammal is a human, dog, bovine, porcine, or horse.

Fig. 1A

ATTCTTCTAATACCGATATTCTCTCAATTTCCAAATGCAAGTGATAGCCACGGGTTAGCTTCCACACTCAACC 1224
D S S N T D I L S I S N A S D S H G L A S T L N
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Q G N V K V T A S I G G I Q G S T D F T V T Q A
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A L T S I E V S P V L P S I A K G L T Q K F T A
TCGGGATTTTACGGATAATTCTAAAGGATATTACGGATCAAGTCACTTGGAAATCTTCTTTCAGCAATCG 1440
I G I F T D N S K K D I I D Q V T W N S S A I
TAAGCGTGTCTAACTTAGACGACAAATAAGGCTCTGGAAAGCTCACGCTGTTGGAGACACGACTATTACCG 1512
V S V S N L D D N K G L G K A H A V G D T T I T
CAACCTTAGGAAAAGTTTCAGGTAAACTTGGCTTACTGTAGTTCCCTGCGGTTCTCACTTCTATTCAAATCA 1584
A T L G K V S G K T W L T V V P A V L T S I Q I
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N P V N P S L A K G L T Q K F S A T G I Y S D N
CTAACAAAGGACATCACTTCCGCTGTACGTGTTCTCATCCGATTCCTCAATCGCGACGATTTCAAAACGCC 1728
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Q K N Q G N A Y G A A T G A T D I K A T F G K V
GTAGTCCGGTTTCTACGTTATCTGTACAGCTGCAAGCTTGTTGAAATCCAAATCACACCGGCTGCTGCTT 1872
S S P V S T L S V T A A K L V E I Q I T P A A A
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S K A K G L T E R F K A T G I F T D N S N S D I
CAAATCAAGTTACTTGGAATTCCCTCTAATACGGATATTCTTACCGTTTCCAAACACAAACGCCAACGCGGAT 2016
T N Q V T W N S S N T D I L T V S N T N A K R G
TAGGTTCCACTTTAAACAAGGAACCTGTTAAAGTTACCGCTTCTATGGGTGGAATCGAAGATTCTGTAGATT 2088
L G S T L K Q G T V K V T A S M G G I E D S V D
TTACCGTCACACAGGCGACTTTTGACTTCGATCGAAGTCTCTCCAACTCGCGCTTCGATTGCAAAAGGAATGA 2160
F T V T Q A T L T S I E V S P T R A S I A K G M
CTCAAAAATTTACGGCTACAGGTATTTTACGGATCATTTCTAAGAAAGAACATTACAGAGCAAGTCACCTGGA 2232
T Q K F T A T G I F T D H S K K N I T E Q V T W

Fig. 1B

Sheet 3 of 28

AGTCTTCTCGAAAGCATTAAGTATGTTGAATGCACCTGGTGAAGAAGGAACAGGTAAGGCGATTGCAGTTG 2304
K S S K A L S M L N A P G E G T G K A I A V
GAAACACATTACTGCAACCTTAGAAAACCTTCCGGGAAACAGATATTACCGTTACTCCCGCAATT 2376
G K H Y Y C N L R K T F R E N R Y Y R Y S R N
CTTACTTCAATTCAAAATCAGTCCTGTAAACAAATGTTCTTGTCAAGGGTTAACAGAAAAATTTCTGCTA 2448
S Y F N S N Q S C K N I V L V K G L T E K F S A
CAGGTATCTACTCTGATAATTCCAGCAAGGACATCACTTCCGCTGTACGTGGCATTCGTCCAACAACCTCTG 2520
T G I Y S D N S S K D I T S A V T W H S S N N S
TTGCAACGATCTCAACACACAAAGGTTACCAAGGACAGCTCACGGAACCGGTACAGGAACAGTGGATATTA 2592
V A T I S N T K G Y Q G Q A H G T G T G T V D I
AAGCGACATTGGGAAATGTAAGCAGCCAGGTTTCCAGATTATCCGTTACCGCAGCGGAACCTTATTGAGATTG 2664
K A T L G N V S S Q V S R L S V T A A E L I E I
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V L D P T S S H K A K G L T E N F K A T G V F T
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D N S T K D I T D Q V T W K S S K T A Y A K I S
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S I S A N A T F Q V T P A K V V S I E V I P N
ACATATCTTTTGCAAAAGGAACAGTTATCAATTCAAGCAACTGGAATCTACACGGATCATTCAGAAGCAG 3024
N I S F A K G N S Y Q F K A T G I Y T D H S E A
ACATTACTGAACAGGTAACCTGGTCTTCCTCGAATCCGAAATCGCATCAGTAGAAAACACCTTCGGATCAG 3096
D I T E Q V T W S S S N P K I A S V E N T F G S
CTGGTTTGGTTAACACAACCAATATTGGAAGTACGAATATCACTGCAAGTTATCCGATACCGTATCAGGTG 3168
A G L V N T T N I G S T N I T A K L S D T V S G
CTTCTGTTTGAATGTCACCTCCAGCGCTTCTCGTTACATCATGATAACTCCGAGTTATGCAGGTATTGAGA 3240
A S V L N V T P A L R Y I M I T P S Y A G I E
AAGGTTATACAAAACAATTTTCAGCGGATAGGCACCTTACTCCGGATCAATCTACCAAGGATTGACTGAGGATG 3312
K G Y T K Q F S A I G T Y S D Q S T K D L T E D

Fig. 1C

TAACTTGGTTCTCCTCCCAATCCTTCTAGTGTTGTAATTGAAACACACTCCCGGCAAAAGGTCTCGCGTTCCG 3384
V T W F S S N P S S V V I E N T P G K K G L A F
CTTCTGAATTAGGAGAACCCGACATTACGGTATTCTACGATCACCACACTCAGAGTTCTTATACTCCAGTTA 3456
A S E L G E P D I T V F Y D H H T Q S S Y T P V
CGGTACGGAAAGTGGTATAGTAAATACATACTATTAGTCTTTCTTCCATTTCGAAACCAAGGTTCAACCC 3528
T V T E S G I V N I T I S L S I S K T K G S T
ATCAATTTAAAGCTACCGGAAAGTTTGAGAAATGAGATCTCAGTGAACCTTGTAACCTTGGAGTT 3600
H Q F K A T G K F E N G A E I D L T E L V T W S
CTTCCAATCCTACGGTGGTTTCTATTAGCAATGTTGATGACGAAAGAGGTTTGGCAACTGCTCTTTCCGTAG 3672
S S N P T V V S I S N V D D E R G L A T A L S V
GTTCCCTCCAAAATATCTGTAGATTACAATTCTATCAGTAGCTCTATCGATTTTGAAGTAACTCCAGAAATAT 3744
G S S K I S V D Y N S I S S I D F E V T P E I
TAGCCTCTATTAAACCGGAGCCATACATGAACAATTAAACAATGTTTACACATTCGCAAAAACAACAAT 3816
L A S I K T E P
GAGTTCGTGACCTTTCTTTATTACGAATTCATTGAGTTATTGAATAACGCCGATTATTATGGAAAGGAGCA 3888
ACTCAAGTTTATCGGTATGATTGTAAACCTATCGACCTTGTGATCGTTTCTTCTTCTAACTTTTGTTCCT 3960
AAAAACACGCCGCAGATTCTGCGGAGTGTTTTT 3993

Fig. 1D

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Fig. 2

Liga-1
 Liga-2
 Liga-3
 Liga-4
 Liga-5
 Liga-6
 Liga-7
 Liga-8
 Liga-9
 Liga-10
 Liga-11
 Liga-12
 Igl1
 Igl2

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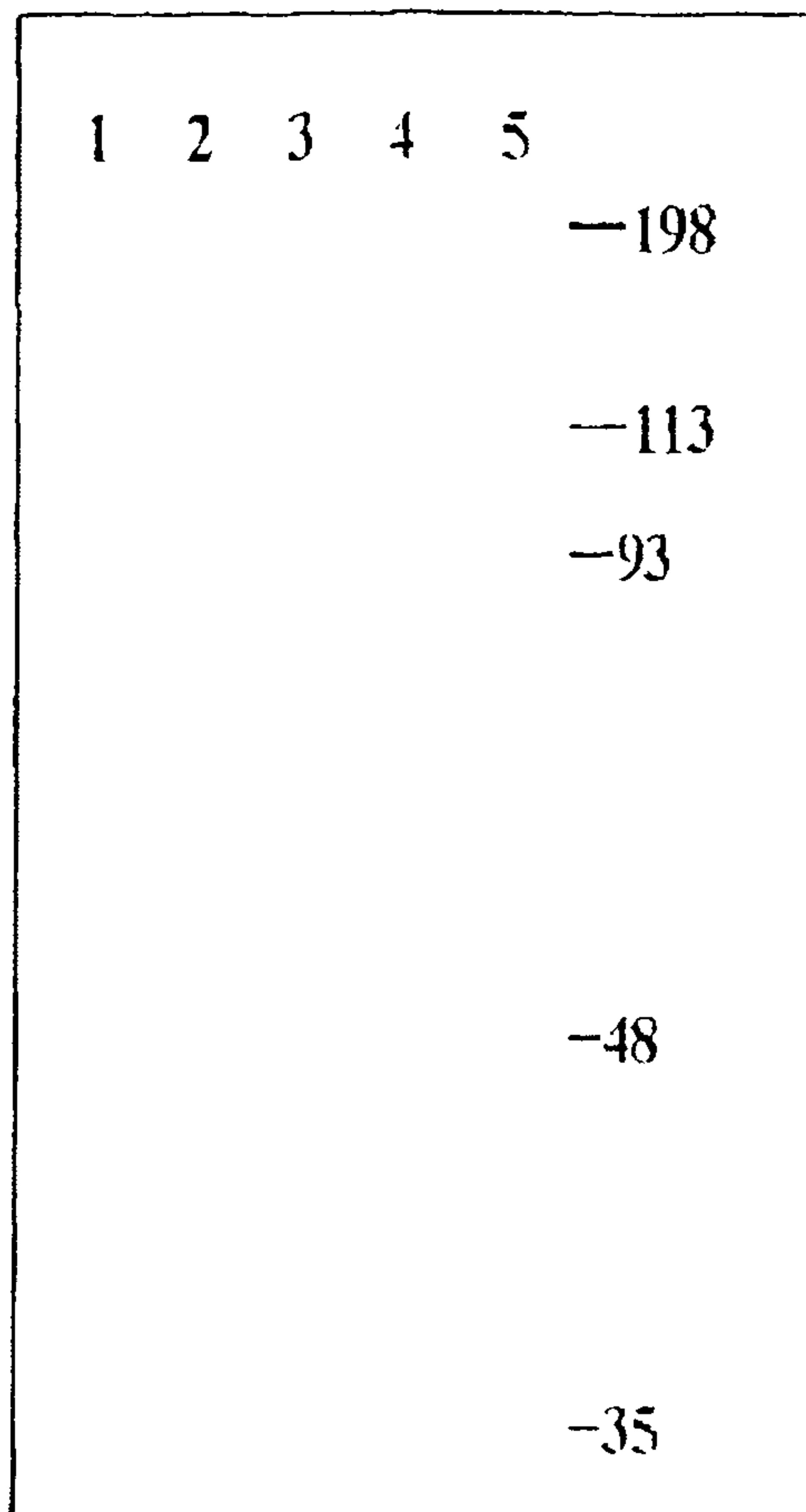
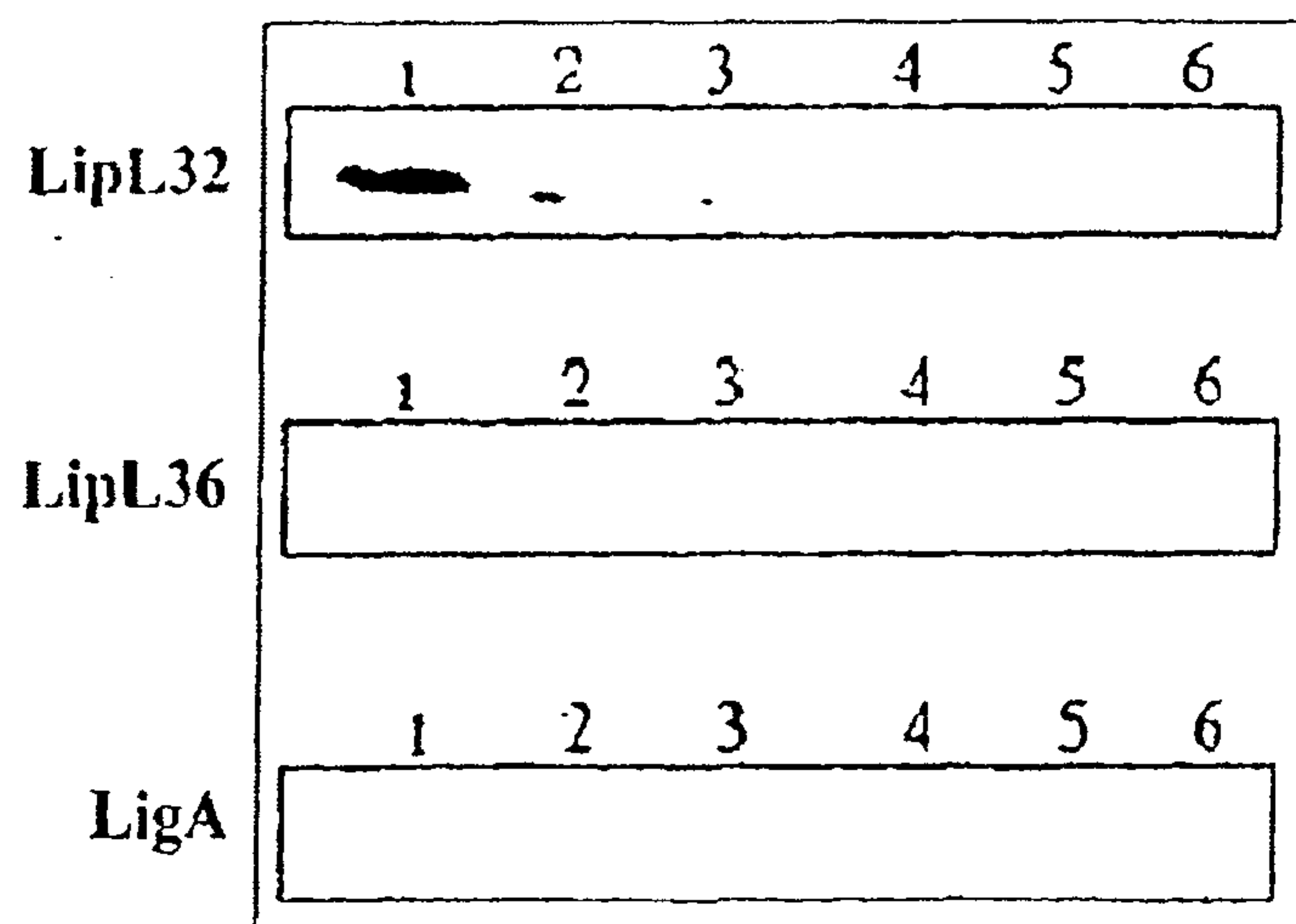
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 [A]v[LS]q[IQ]V[TS]nnp[n]i[p]lg[k]Q[k]i--[AT]GIYSDNSr[DI]ss--[V]i[W]n[SS]Nst[IA]n[I]q
 [A]a[LV]S[IS]M-[SP]tnstv--[AK]GLqen[F]A[AT]GI[F]TDNSn[SD]ITd[Q]--[V]TWd[SS]Ntd[IL]s[IS]
 [A]a[LV]S[IE]V-[SP]v[i]p[SI]--[AK]GLTq[k]FtA[IG]I[F]TDNSk[KD]ITd[Q]--[V]TWn[SS]Sai[V]sv--[S]
 [A]v[LV]S[IQ]in-[P]vn[P]S[LI]--[AK]GLTq[k]FtA[IG]I[F]TDNSN[KD]ITsa--[V]TWf[SS]Sds[IA]TIS
 [A]k[LV]e[IQ]it-[P]aa-[As]k-[AK]GLTer[F]A[AT]GI[F]TDNSn[SD]ITn[Q]--[V]TWn[SS]Ntd[IL]T[VS]
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 sgi[vn]I[ti]-[S]lssi[S]kt--[K]GsthQ[F]A[AT]Gk[feng]aei[D]ITel--[V]TWs[SS]Np[t]Vys[IS]
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 vv-[TS]vtV-[P]tt-[As]v-[AK]GaTlQ1t[AT]vtp[SS]akvtgk--[V]TWt[SS]Np[SV]ATVv

Liga-1
 Liga-2
 Liga-3
 Liga-4
 Liga-5
 Liga-6
 Liga-7
 Liga-8
 Liga-9
 Liga-10
 Liga-11
 Liga-12
 Igl1
 Igl2

83
 86
 90
 89
 91
 90
 90
 91
 91
 91
 92
 91
 80
 81

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 [N]as-----[GL]tctavaag[AT]ITATsGdg--[S]satg--[V]T-

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*Fig. 3**Fig. 4*

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Fig. 5C

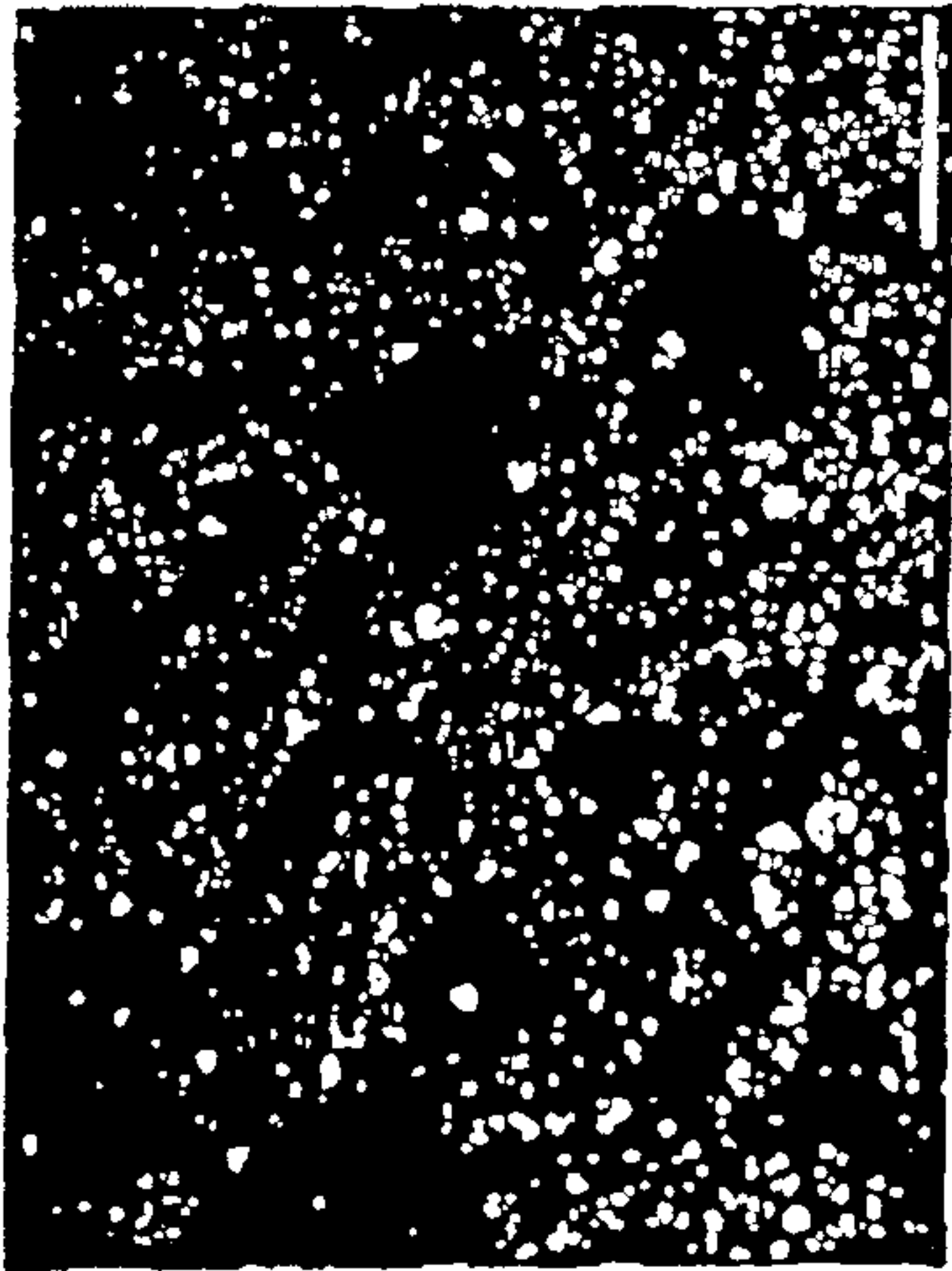


Fig. 5B



Fig. 5E

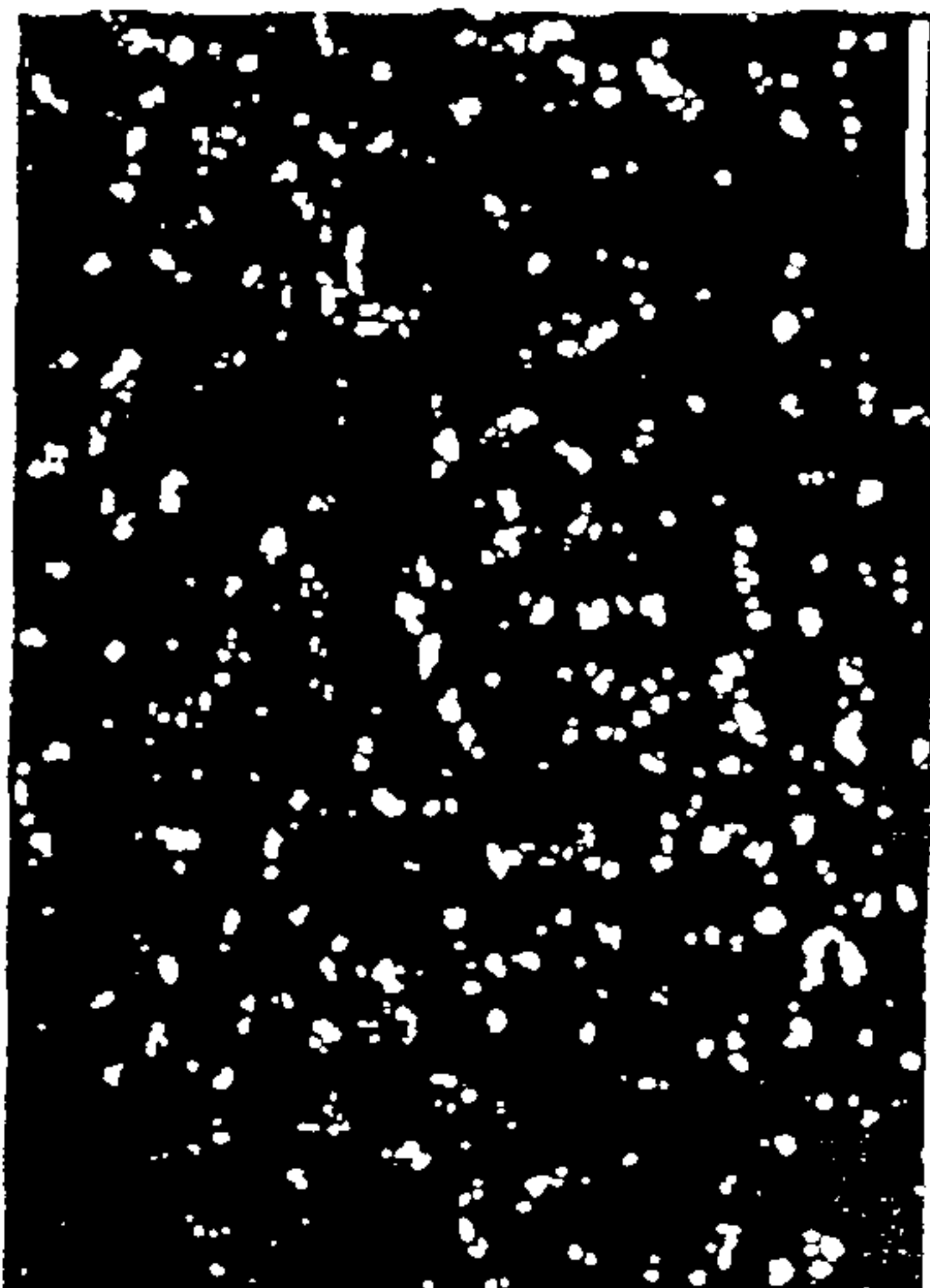


Fig. 5A

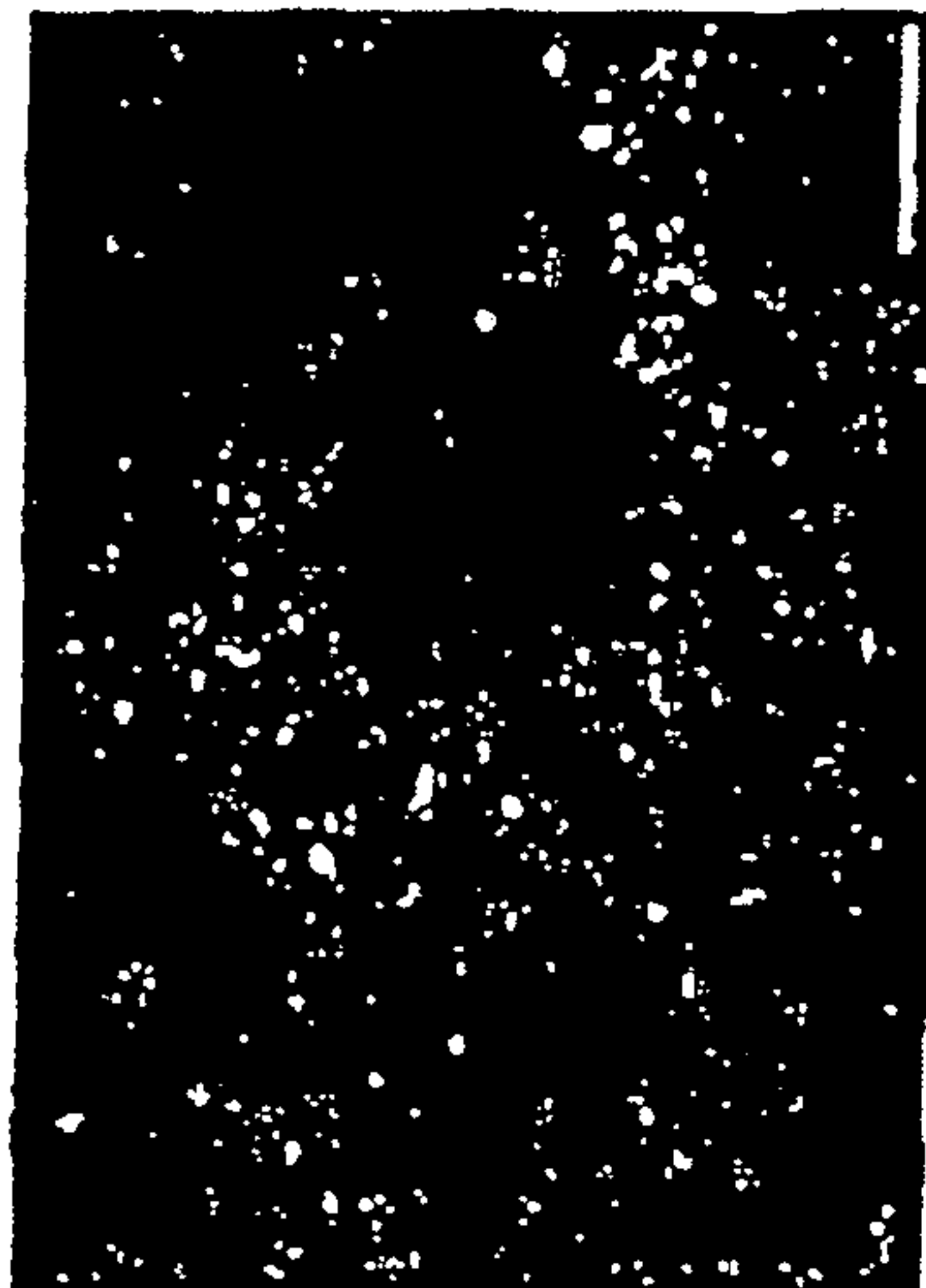


Fig. 5D

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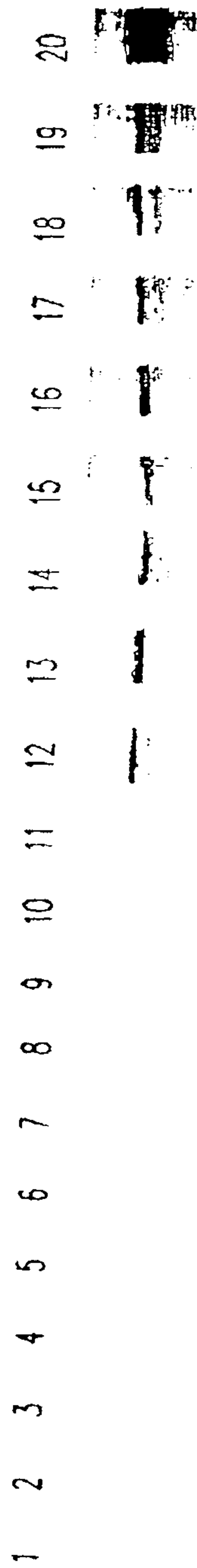


Fig. 6



Fig. 7A

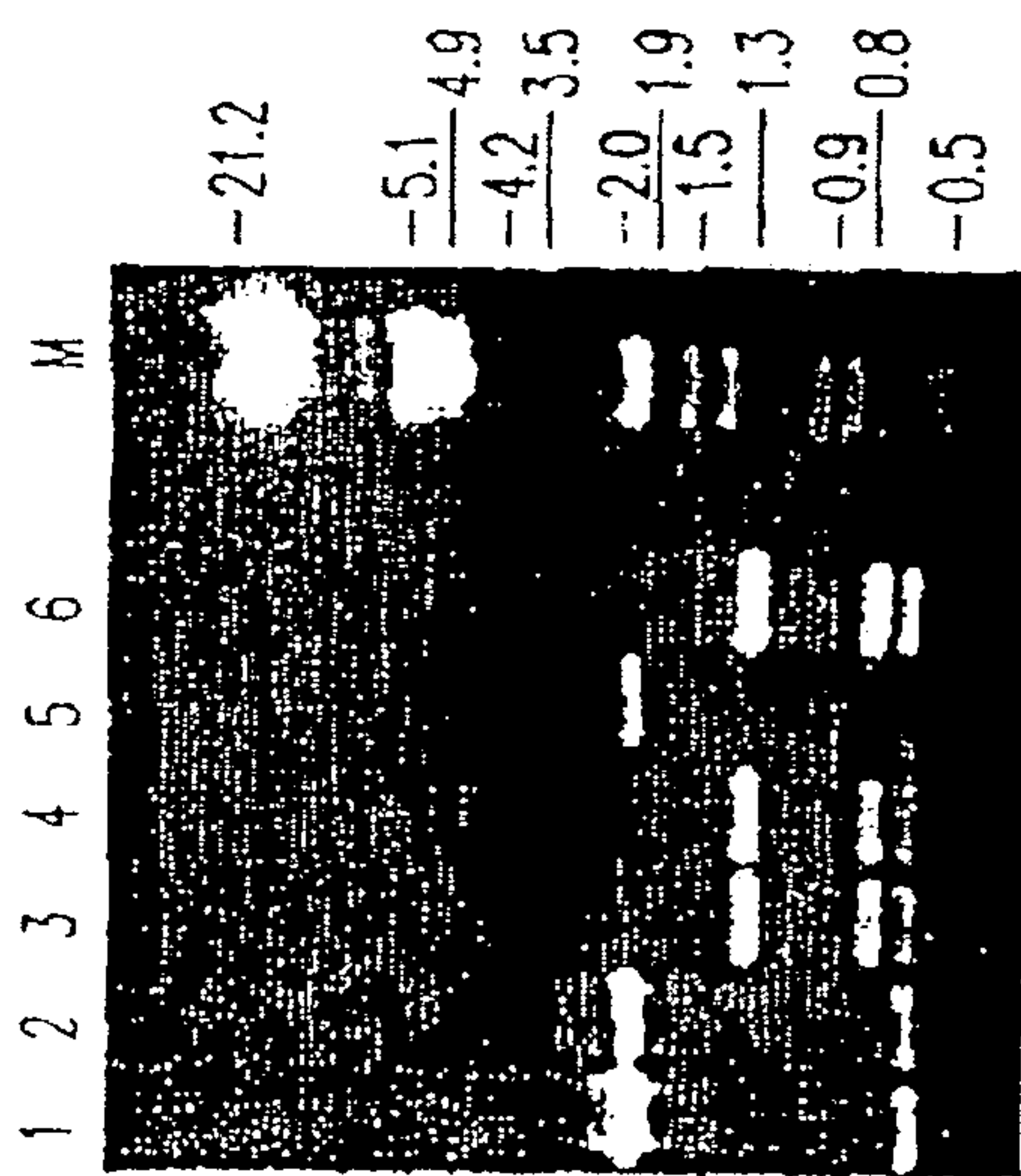


Fig. 7B

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 216
 288
 360
 432
 504
 576
 648
 720
 792
 864
 936
 1008
 1080
 1152

GTATGCTTGGCCACTTTTAAACCGGCTCTGCTAGGATTAAACCGCTGTAATAAAGTAATGGGCTGTCTTTT
 C M S W P L L T G L V G L T A G K S N G L S F
 TCCACCTTCTGTAGGTAACCTCTAATCCGACTATTAACAAGAAATCGAACTCAGTTATCAAGATTCTGTCTATCG
 F H L L G N S N P I I T R I E L S Y Q D S S I
 CAAACGGTACCAGTACAAACCCCTAGAAAGTTACCGCAATCTTTGATAACGGAACAATCAGAATATTACGGATT
 A N G T S T L E V T A I F D N G T N Q N I T D
 CGACATCCATCGTCCCGATTCCCAATCCGTTGTAAACCAATCCAAAGTAACAGAGTCAGAGGAATCGCTTCTG
 S T S I V P D S Q S V V T I I Q G N R V G I A S
 GTTCTCCATTATAAAGCAGAAATATAACGGCCCTGTACTCTGAACAAATAATACAGTTACACCCAGCCACTC
 G S I I K A E Y N G L Y S E Q K I T V T P A T
 TTAACCTCAATTCAAGTTACGAGTTTAGAGTCAGGTATACCTAAAGGTACTAATCGTCAATCTCTCAGCCA
 L N S I Q V T S L E S G I L P K G T N R Q F S A
 TCGGTATCTTTTCGGATGGTTCTCATCAGGATATTTCCAAACGATCCATTGATCGTTGGTCCCTCCAGTAATC
 I G I F S D G S H Q D I S N D P L I V W S S N
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 P D L V Q V D D S G L A S G I N L G T A H I R A
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 N R D I S S S V I W N S S N S T I A N I Q N N G
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 I L E T A D T G I V I I S A S E N I I G S V K
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 L I V T P A A L V S I S V S P T N S T V A K G L
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 Q E N F K A T G I F T D N S N S D I T D Q V T W

Fig. 8A

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ATTCTTCTAATACCGGATATTCTCTCNAATTCCNAATGCAAGTGATAGCCACGGTTAGCTTCCACACTCAACC
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Q G N V K V T A S I G G I Q G S T D F T V T Q A
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I G I F T D N S K K D I T D Q V T W N S S A I
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A T L G K V S G K T W L T V P A V L T S I Q I
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N P V N P S L A K G L T Q K F S A T G I Y S D N
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S N K D I T S A V T W F S S D S S I A T I S N A
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S K A K G L T E R F K A T G I F T D N S N S D I
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I T N T L T P G S S E I S A A L G S I K S S K V
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I L K V T P A Q L I S I A V T P I N P S V A K G
TAATACGACAATTAAAGCCACCGGAACATATACGGATCATTCGGTACAAAGACGTGACCTGACCTACCT
L I R Q F K A T G T Y T D H S V Q D V T A L A T
GGTCTTCTCCAAATCCAGAAAGCAATGGTTAAACAACGTTACAGGTTTCGGTTACAACAGTGGCTACCGGAA
W S S N P R K A M V N V T G S V T T V A T G

Fig. 8B

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ATACAAATATTAAAGCAACGATAGACTCCATATCCGGCTCTTCCGTTTGAATGTCACTCCTGCACTTCTTA
 N T N I K A T I D S I S G S S V L N V T P A L L
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 T S I E I T P T I N S I T H G L T K Q F K A T G
 TCTTTTCAGATAAATCTACTCAAAATTGACTCAGCTTGIAACTTGGAATTTCTTCCGATCCATCTAAGATTG
 I F S D K S T Q N L T Q L V T W I S S D P S K I
 AGATCGAAACACTTCCGGTAATAAGGATAGCGACAGCCTCTAAATTAGGAAGTTCGAATATTAAAGGCCG
 E I E N T S G K K G I A T A S K L G S S N I K A
 TCTACAAATTCATCCAAAGCTCCCAATTCCGATTACAGTCACCTGACTTAAAACTGAAAGTATACTATCA
 V Y K F I Q S S P I P I T V T D L K L K S I T I
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 S P S S S I A K G L T Q Q F K A I G T F I D G
 CTGAACAAGAAATTACGAATCTTGACCTGTGATTTCTCCAAATCCGACGTTGCCCTATCAATAACGCTG
 S E Q E I T N L V T W Y S S K S D V A P I N N A
 CCAATGAAAAGGTTTAGCAACCGCACTTTCAATAGGTTCTTCCGACATCTATCGGATTTACAATTCTATAA
 A N E K G L A T A L S I G S S D I Y A I Y N S I
 GCAGTAATAAAATAAATTTTAATGTAAGTGCTGCCAGTTAGATTCCATTAAATCAACCCGTCATAACA
 S S N K I N F N V S A A T L D S I K I N P V N N
 ACATTGCGAAAGGCTTACACAACAATATACGCGCTCGGTGTTTATTCCAGATTCCTCACTATTCAGGACATCA
 N I A K G L T Q Q Y T A L G V Y S D S T I Q D I
 GCGATTACCTGCTAGCTCCAAATTCCTCAATTAGTATTTCCTCAATTCGACCGAAACCAAGGAA
 S D S V T W S S S N S S I S I S N S T E T K G
 AAGCGACCGCTTTACAGATTGGAAACAGCAAAATCACTGCGACTTACAATTCCATTTCGGAACACATAGACA
 K A T A L Q I G N S K I T A T Y N S I S E N I D
 TAACCGTCAGCGCAGCAACCTTTCTCGAATTCAATATCTCCTATCAATACAAATATAACACACACCGTAT
 I T V S A A T L S S I S I S P I N T N I N T T V
 CAAAACAATTCTTCGGGTGGGAACCGTATTTCGGATGGAACCAAGCGGATTAACTTCTTCGGTTACATGGT
 S K Q F F A V G T Y S D G T K A D L T S S V T W
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 S S N Q S Q A K V S N A S E T K G L V T G I A
 CTGGAAATCCTACCATCATAGCGACCTACGGTTCAGTATCTGGAAATACAAATCCTCACAGTAACAAACGCG
 S G N P T I I A T Y G S V S G N T I L T V N K T

Fig. 8C

Sheet 12 of 28

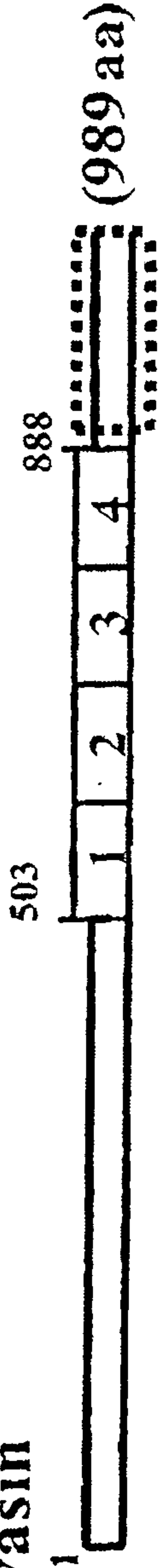
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D T I A P T V Q S V V S L S P T T I Q V V Y S E
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S I N N K E A L D L S N Y K I I N S S N F I G H
GTTCAGATAATACGGACTTCAATTCCCAATCTCAAAACCGCAGATTTTTCTCTTAGTAGTATCAAGGAAGTA 3672
C S D N T D F N S N S Q T A D F S L S S I K G S
NAAATACTTTTACGATCACACTTTTACACATTTACACAAATTTTAAACAAATCATACACACTCGTAGTCAACAAAC 3744
K N T F T I T L S H S Q I L N K S Y T L V V N K
AAGGAATTCACGATCTTTCTTCCATTCCAAATCTTTAAGTGTCCAAATAACTCTGATTTTATGGGAAAAG 3816
Q G I H D L S S I P N S L S C P N N S D F M G K
AACAACTCAAACTTACAAGTGCAGTTTGTAAATTCCTTAAACCAAGTGATCGTTTCTTTTCCAAACCTTTAT 3888
E Q L K L T S A V C N S L N Q V I V S F S K P L
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Y S G K E V T K S V E C S N P S Q C E S R Y K F
CAGGTGTCTTCAATTGGGAAGTATTACGAGCGTTAGAAATTTTAGATGGAAAGGTATCGGTGGAGCGCCGG 4032
A G V S S L G S I T S V R I L D G K V C G G A P
CAGACTCCTCGAAAATATGTTTAACTCACTCCCTTCTTCAATCAGGTGGTCAATATACGATCATCGCCGCAA 4104
A D S S K I C L T H S L L Q S G G Q Y T I I A A
ATGATTTAAACGGAGACGGCTTTTGACAAACAATCCCTGGGAGCAATTCGAGATTTCATTCGATCAAGAAACC 4176
N D L N G D G F D N K S W G A I R D S F D Q E N
TACAACCTTCTCCAAAGATAGAAATCAACTTTATAGGTGCGGAAATTCCTCTCAACTTTTATGGATGCC 4248
L Q P S P K D R I N F I G C G N S P L N F M D G
CAATCGTGTGATCCTTTTGGAGACGGTTCCGACTTCGGCTCTCTTGTAGATTACAAACAATCAATCTATC 4320
P I V S D P F G D G S D F G S L V D Y N N Q I Y
TAGGACCGAACGTAAAGGAACCAAGCCCACTCGATTCCATTATGACGGAACCTTTCCGGAATCTATTTTC 4392
L G P N V K G N Q A N S I P L
TTTCTTTTACCAAGATATAATGCCCTTAACCGTGCTTCTCCTCAAAAGATGGAGNATCCCGGTCCGAATTAC 4464
GTACGATGGGCATACGGTTGTACTCTCAATACTGCAGACATACTACTCGATGTGTCGGATAACGAAATCG 4536
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Fig. 8D

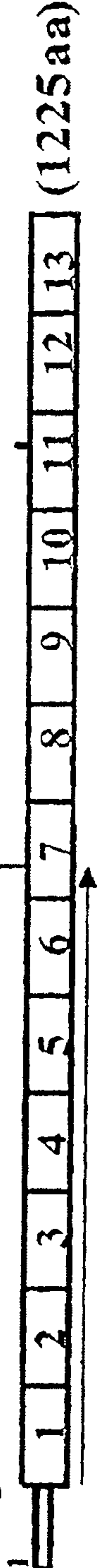
Tir and intimin complex



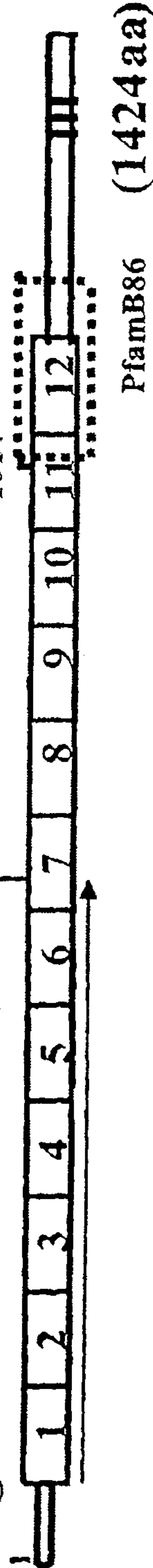
Invasin



LigA



LigB



PfamB86 (1424aa)

Fig. 9

LigB1 ti-TrIeIsyqdsSIAh---GsttleVtAIFdngtNqNITdtsiVpdsqSvvtIqgn 55
 LigB2 tLh-SIqVtslesqILp---KgtNrQESaIGIFSDgShQDIsndpliV-WsSSNpdlvqv 55
 LigB3 vLsq-IqVtsnnpnIpI---GkkQkLiATGIYSDnSNrDIss---ViWnSSNstI-An 51
 LigB4 aLv-SIsVspnsvA---XGLqenFKATGIFtdnSNsDItdq---VTWdSSNtdIIs- 51
 LigB5 aL-TSIEVspVlpSIA---XGLTQkFtAIGIFtdnSkkDItdq---VTWnSSsaivsvs 52
 LigB6 vL-TSIqInpvnpsIA---XGLTQkFtAIGIYSDnSNkDItdsa---VTWfSSds-SiAt 51
 LigB7 kLve-IqITpaaasKA---KGLTerFKATGIFtdnSNsDItdq---VTWnSSNtdI-Ae 51
 LigB8 qLi-SIaVTPinpsVA---KGLI-QEKATGTYtdnSVQDvtala---TWsSSNbrk-Am 51
 LigB9 lL-TSIEITPtinsIthgltkQ---EKATGIFSDkstQnltql---VTWISSdp-Skie 51
 LigB10 kLk-SITIsPssSIA---KGLTQQFKaIGTfIdgSeQeITnl---VTWYSSksdv-AP 51
 LigB11 tLd-SIKInPvnnnIA---KGLTQQYtAlGVYSDstiQDisds---VTWSSNs-Ssis 51
 LigB12 tLs-SIsIsPintnInttvsKq---fFAMGTYSdgtkadltss---VTWSSNq-SqAk 51
 Igl1 av-TSvtVspvtvaSll---KgaTlQltATGtpaDasNgk-----VTWSSNt-Svat 47
 Igl2 vv-TSvtVTpttaSvA---KgaTlQltATVTPSSakvtgk-----VTWtSSNp-Svat 48

LigB1 rvr-----GIAsgssik-----AeynglyseqkiTV- 82
 LigB2 dds-----GLAsginl-GtahIraSfqskqGaeenTV- 86
 LigB3 IqNh-----GileTAdt-GivTIsAssenIIGsvklIV- 83
 LigB4 I6NasdsnGLAsTlnq-GnvkvTAsIGGIqGstdfTV- 87
 LigB5 nlddnk---GLgkahav-GdtTtATlGkvsGktwlTV- 86
 LigB6 ISNaqknqGnAygaat-GatdIKATfGkvsspvtl-- 86
 LigB7 ItNtsgskGhtnTltp-GsseIsaAlGsikSSkvlkv 88
 LigB8 vNvtgsvttvaTgnunikaTIdSisGssvlnv----- 84
 LigB9 IeNtsgkkGIATasklGssnIKAvyxfiqsSpipi-- 86
 LigB10 IhNaaneKGLA-TAlsiGssdIyAlynsIssnkinf-- 86
 LigB11 ISNstetKGA-TAlqiGhskItATynsIsenidITV- 87
 LigB12 vSNasetKGLv-TgiasGnptIiATyGsvsGntilTV- 87
 Igl1 vSNst---GLv-TAlakGtatITATSGdgnssatvTV- 80
 Igl2 vvNas---GLtctAkvaaGtatITATSGdgssatgvT-- 81

Fig. 10

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LigAvari	ltvsNTnakrGlgstLkqGtgvkvtasmGgTeds-VdftVTqAtLtStleVsPtraSiAKGm	59
LigBvari	aeitNTsgskGitenTLtpGsseiseaIGsIKsSkvilkVTpAqLiSiAVtPinpSvAKG1	60
LigAvari	t-QkFtATGi fTDHSkknitEqvTwkSSskalSMlNapgeegTgkAiavgkhyyynlrk	118
LigBvari	irQ-FkATGtyIDHSvqdvTalaTIsSSnprkAMvNnvtgsvTtvAtgntnikatidsis	119
LigAvari	tfrenryrnsyfnnsqckniv-LvKgltekfsatgiysdnsskdiIsavtwhSsn	177
LigBvari	gssvlnvtpalltsieitptinsithgLtKqfkatgifsdkstqnlqIvIwissdpSki	179
LigAvari	nsvaTisntkgyqqgahGtgtgtvdiKatlgnvssqvsr-LsvtaaelIeivldptsshk	236
LigBvari	eienTsgkkgiatasklGssnikavyKfigsspipitvtdLklksit-Ispssssiakgl	238
LigAvari	akgltenfkatgvftdnsTkdiTdqvtkssktayakisnatgskrvvnaiSkgdtshisa	296
LigBvari	tqqfkaigtfidgseieiInlvTwysksdvapinnaekglatalsigSdiyaiyns	298
LigAvari	tlgsissaNatfqvtpakvvsievipnnisfakgnsyqfkatgiytdhseaditedqVTWS	356
LigBvari	issnkinfNvsaatlidsikinpvnnniakglTqqytagvysdstiqdisds---VTWS	354
LigAvari	SSnpk-IaSveNtfqsaGlvnctnIGstnITAKlsdtvsgasvlnvtpallryimitpsy	415
LigBvari	SSnsssiI-SisNstetkGkatalqIGnskITATynsiseniditvsaatissisispint	413

Fig. 11A

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LigAvari	agiekgytKQ-FsAiGTYSDqstK-DLTedVTWfSSNpSsvvientpgkKGLafaselGe	473
LigBvari	ninttvs-KQfF-AMGTYSDg-TKaDLTssVTWfSSNpSsqakvsnasetKGLvtgiasGn	470
LigAvari	PdItvfydhhtqssytpvTVtesgivniTislsissktkgsthqfkatgkfengaeidl	533
LigBvari	PtIiatYgsvsgntil--TVnktdtiapTVqsvslspttiqvvyssesinnkealdlsny	528
LigAvari	elvtwsSSNptvvsisNvdderglaTAlsvgSSkisdynsisssidfevtpeillasikt	593
LigBvari	kiin--SSNfighcsdNtdfnsnsqTAdfsSSikgskntftitlshsqilnksytlvvn	586
LigAvari	ep-----	595
LigBvari	kqgihdlssipnslscpnnsdfmgkeqlkltsavcnslnqvivsfskplysgkevtsve	646
LigAvari	-----	595
LigBvari	csnpsqcesrykfagvsslgsitsvrildgkvcggapadsskiclthslqsgggqytia	706
LigAvari	-----	595
LigBvari	andlngdgfdnkswgairdsfdqenlqpspkdrinfigcgnspInfmdgpivsdpfgdgs	766
LigAvari	-----	595
LigBvari	dfgslvdynnqiylgpnvkgnqansipl	794

Fig. 11B

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TAGAATATACTTTGTTTTATAAATTTTAAATGTTTTATTAAAACTTTTACATCCAATAAATCTCAA 72
 GAGAACTTCTATAAAATTAATTTTTGTGTAGATGCGCAACAACGACTTGATGCAAAATCTAATTGGATA 144
 ATTATCCTTTTTAAATTTTGTAGAGGCTCTCAATAAATAAACACAGCAAATACACAAATGAAACTTCAAA 216
 TAAACAATTAGAGTGAGTGTATTATGAAGAAATATTTGTATTTCGATTTTCTTTTCGATGTTTTTCAAA 288
 M K K I F C I S I F L S M F F Q
 GTTGTATGCTTGGCCACTTTTAACCACTCTAGCGGGTTTAGCAGCTGGCAAAAGAGGCGGAGATTCATCTT 360
 S C M S W P L L T S L A G L A A G K R G G D S S
 TTTTCCACCTTCTGTTAGGTAACCTCAATCCGACTATTACAAGAATCGAATCAGTTATCAAGATTCITCTA 432
 P F H L L L G N F N P T I T R I E L S Y Q D S S
 TCGCAAACGGTACCAGTACAGCCCTAGAAGTTACCGCAATCTTTGATAACGGAACAAATCAGAATATTACGG 504
 I A N G T S T A L E V T A I F D N G T N Q N I T
 ATTCGACATACATCGTCCCCGATTCCCAATCCGTTGTAACCATCCAAGGTAACAGAGTCAGAGGAATCACTT 576
 D S T Y I V P D S Q S V V T I Q G N R V R G I T
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 S G S S I I K A E Y N G L Y S E Q K I T V T P A
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 I L N S I Q V T S L E S G I L P K G T N R Q L S
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 N P D L V Q V D D S G L A S G I N L G T A H I R
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 L Q E N F K A T G I F T D N S N S D I T D Q V T
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 T W S S S N P G K A M V N N V T G S V T T V A T
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 G N T N I K A T I D S I S G S S V L N V T P A L
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Fig. 12A

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L T S I E I T P T I N S I T H G L T K Q F K A T 2664
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I B I E N T S G K K G I A T A S K L G S S N I K 2808
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A V Y K F V Q S S P I P I T V T D L K L K S I T 2880
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G S E Q E I T N L V T W Y S S K S D V A P I N N 3024
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A A N A K G L A T A L S I G S S N I S A I Y N S 3096
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N N I A K G L T Q Q Y T A L G V Y S D S T I Q D 3240
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G K A T A L Q I G K S K I T A T Y N S I S E N I 3384
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D I T V S A A T L S S I S I S P I N T N I N A T 3456
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A S G N S I I T A T Y G S V S G N T I L T V N K 3672
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E S I N N K E A L D L S N Y K I I N S S N P I G 3816
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AACAAGGAATTCAGGATCTTTCTTCCATTCCAATTCCTTAAGTTGTCAAATAACTCTGATTTTATAGGAA
K Q G I H D L S S I P N S L S C P N N S D F I G 4032
AAGAACAACCTCAAACCTTACAAGTCCAGTTTCTAATTCCTTAAACCAAGTGATCGTTCTTTTCCAAACCTT
K E Q L K L T S A V C N S L N Q V I V S F S K P 4104
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F A G V S S L G S I T S V R I L D G K V C G G A 4248
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P A D S S K I C L T H S L L Q S G G Q Y T I I A 4320
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A N D L N C D G F D N K S W G A I R D S F D Q E 4392
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N L Q S S P K D R I N P I G C G N S P L N F N D 4464
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Q P I V S D P P G D G S D F G P L V D Y N N Q I 4536
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Y L G P N V K G N Q A A R F N Y D G T P P E S I 4608
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F F S F T Q D I N A T N R A S S R D G G I P V P 4680
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N Y V T I G H T G C T L N S A D I T T G C G P D 4752
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K P K S P N Y L Y Y S S D T D T N L N F K Y I S 4896
TGGGAAAAATTACTGGATTGGCGACTGCAGGAACCTTCATCTATCGCAGTCTAGACGATCGGATCCATGTGG
M G K I T G L A T A G T S S I A V L D D R I H V 4968
GTTTTGCAAAAAAATCAAATCTAAACGCACCTGATTTCGGTAAATCACCTTTAATACATCCGAGCACA
G F A K K N Q N L N A P D F G K I T F N T S E H 5040
ATCGATGTCAATTTGTAACAACCTGTGAAGCCTCTGACGGATACCGCGGTAATCGTTTTAGAAATCGATAGAA

Fig. 12B

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N R C A I V N N C E A S D G Y R G N R F R I D R
 TGCCTTACTTTGGCGGCGGCTCCGTGGATGTAGTCAATTATAGATCTTATAAATCTGATAACTCCTOGATCA 5112
 M P Y F G G G S V D V V N Y R S Y K S D N S S I
 ACTGGGGTTATTATGTGGGAATAGATTCTCTATTCTGTTTTTAAAGAAAACTTTACGCGCAAACGGAGGAT 5184
 N W G Y Y V G I D S L F V F K E K L Y A A N G G
 TTCCAAATTCACATACATAATGGAAGTATAATACACTCTACCACTGCAAACTCCTAGTCCTTGTGAGGGGATCA 5256
 P P N S L H N G S I I H S T S A N P S P C E G I
 ATCGTTGTTCCAGTTGGAAAGACACAGCACCTAGATCCAATCCAAAGTGGCATAACTCTCCTCATAACAATT 5328
 N R C S S W K D T A P R S N P K W H N S P H N N
 GGTTCCTACTGGAGCTTACAAAGTATCGGAATTTAATTCCGGCGGATAAAGCATTCTCTCAATTCCGAGAAT 5400
 W F S L E L T K Y R N L I P A D K A F S Q F A E
 TTAACGGAAGATTGTATGTAACAAGAACGATCTGCGTAACGAAAGAAGATCACTCCGGAATCAGACAAAGTT 5472
 F N G R L Y V T R T I C V T K E D H S G L R Q S
 TACAACTGTGAAAGGTTGTACGGACGGAAGTTATACAAATCGAAGACCCCAACTTTGGAAATGTGATCCGA 5544
 L Q T V K G C T D G S Y T N R R P Q L W K C D P
 CTCTAACCGGCGATACAACAACCTGTGAAGCAGAAGATTGGTCTTTAGTAGGAGATAATGGAACCGGTTTA 5616
 T L T G D T T T C E A E D W S L V G D N G T G F
 CAACTTTGGAGACAATTCGAATCACAGTATGACGATGATGGTTGCAAGTGGATCTTATCTCTACATAGGTT 5688
 T N F G D N S N H S M T M M V A S G S Y L Y I G
 TTGATAACGAAAACGGAATTCGAATCTGGAGAACAATCTTGAAAATCCGGGAAGTTCATCACACAACCTGGG 5760
 F D N E N G I Q I W R T N L E N P G S S S H N W
 AGCCTATAGGAATAGGTGGATTAAAGAGACGTTACCAATCGTCAAATTTATTCCGGCTATATCCGGAATGAATT 5832
 E P I G I G G L R D V T N R Q I Y S A I S G M N
 TTGGTGTAATTTCTGATATATAAGCGTAGGAAACAAAAATAAACCGGTCAAATTTACAGACAACAGAATC 5904
 P G V N F V Y I S V G N K N K P V K I Y R Q Q N
 AATAATATGCAAAATTCATTAAGAATCATCGTGACGATAATGGCTTGATGTTTACCGGATTAATCTCCTGT 5976
 Q -
 AAAATAAACGAAAATTCAGAAAGGCTTATATTCGATCA 6014

Fig. 12C

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LiqB1
 LiqB2
 LiqB3
 LiqB4
 LiqB5
 LiqB6
 LiqB7
 LiqB8
 LiqB9
 LiqB10
 LiqB11
 LiqB12
 Ig11
 Ig12

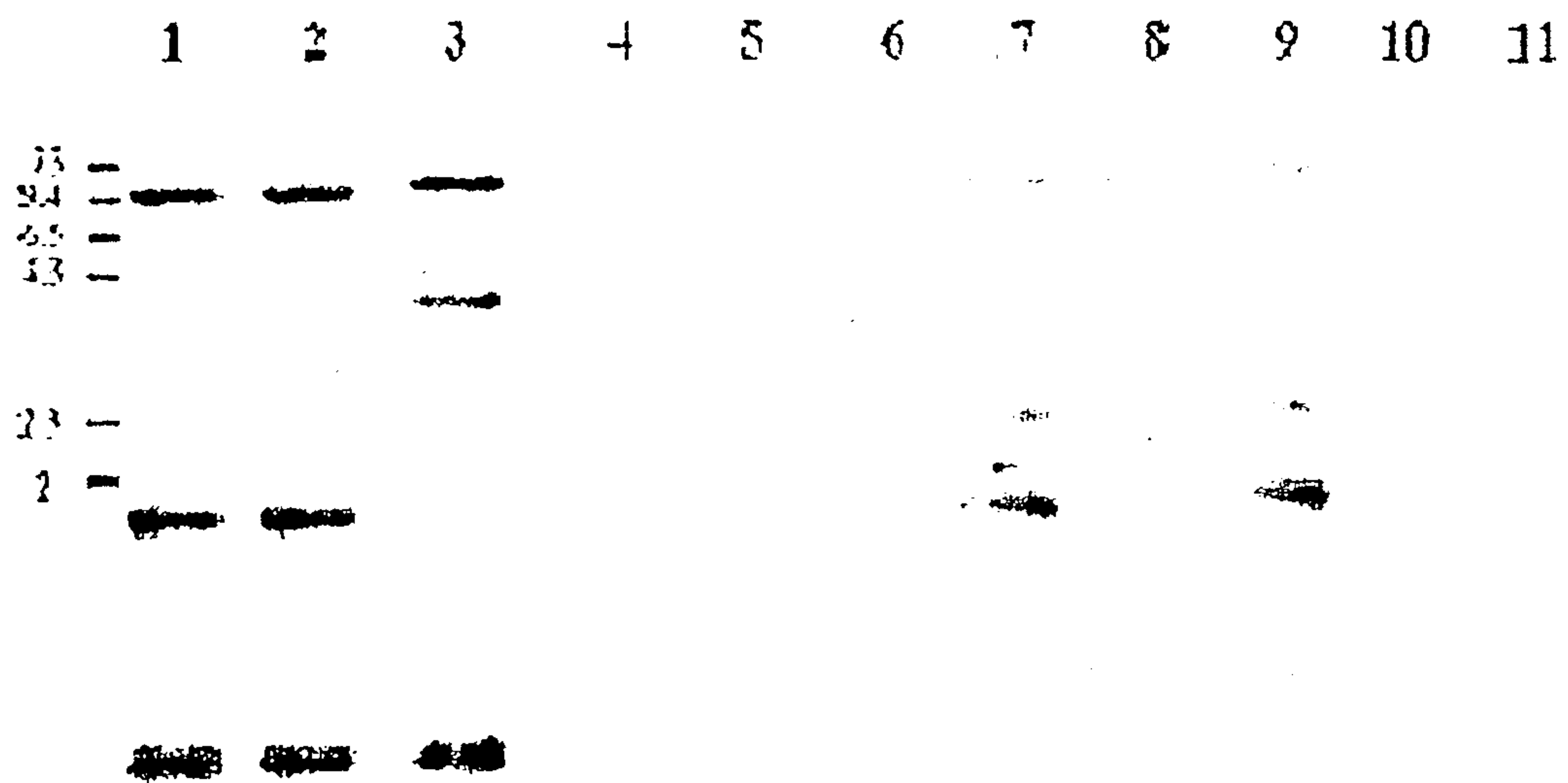
LiqB1
 LiqB2
 LiqB3
 LiqB4
 LiqB5
 LiqB6
 LiqB7
 LiqB8
 LiqB9
 LiqB10
 LiqB11
 LiqB12
 Ig11
 Ig12

F9 13A

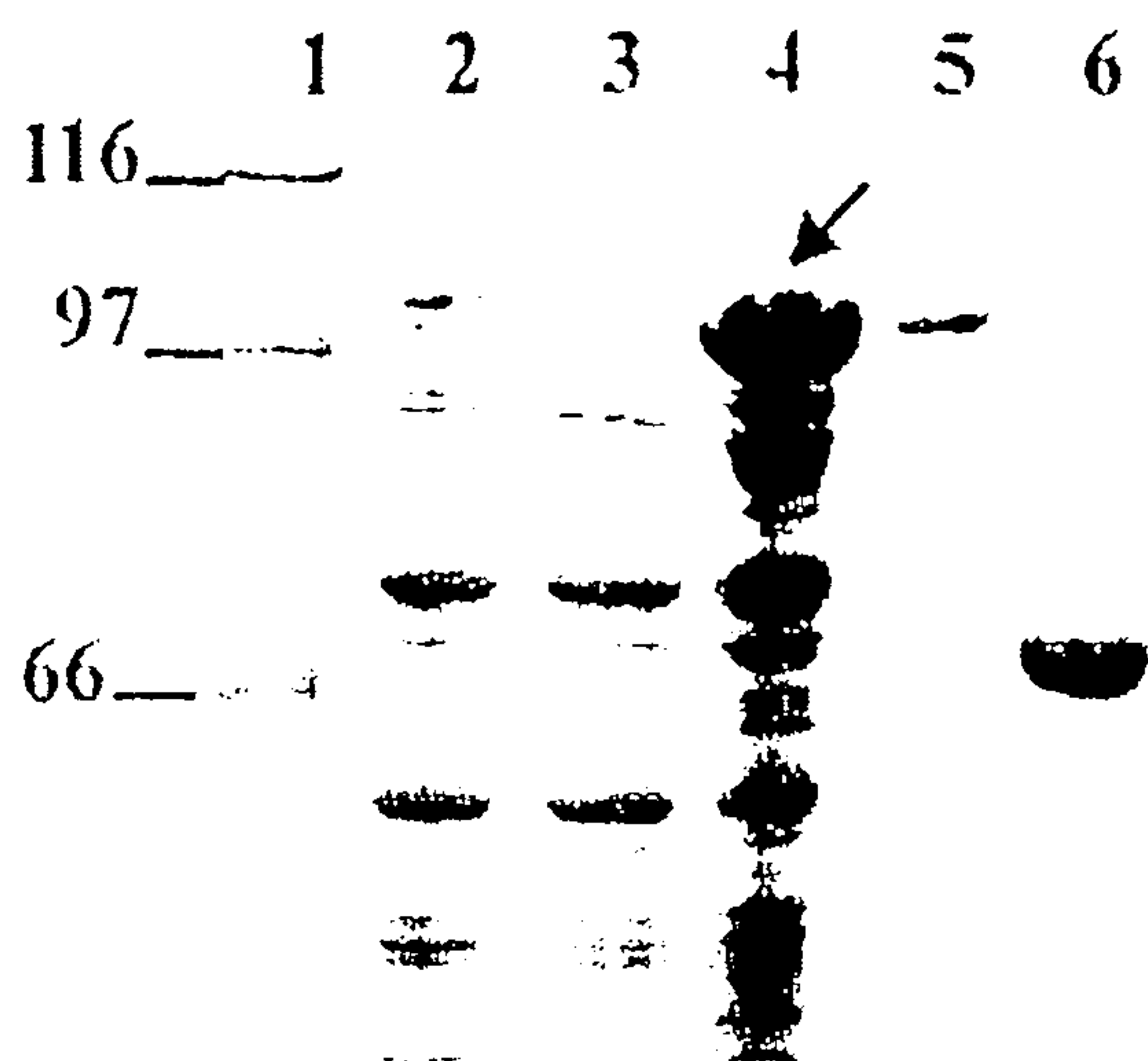
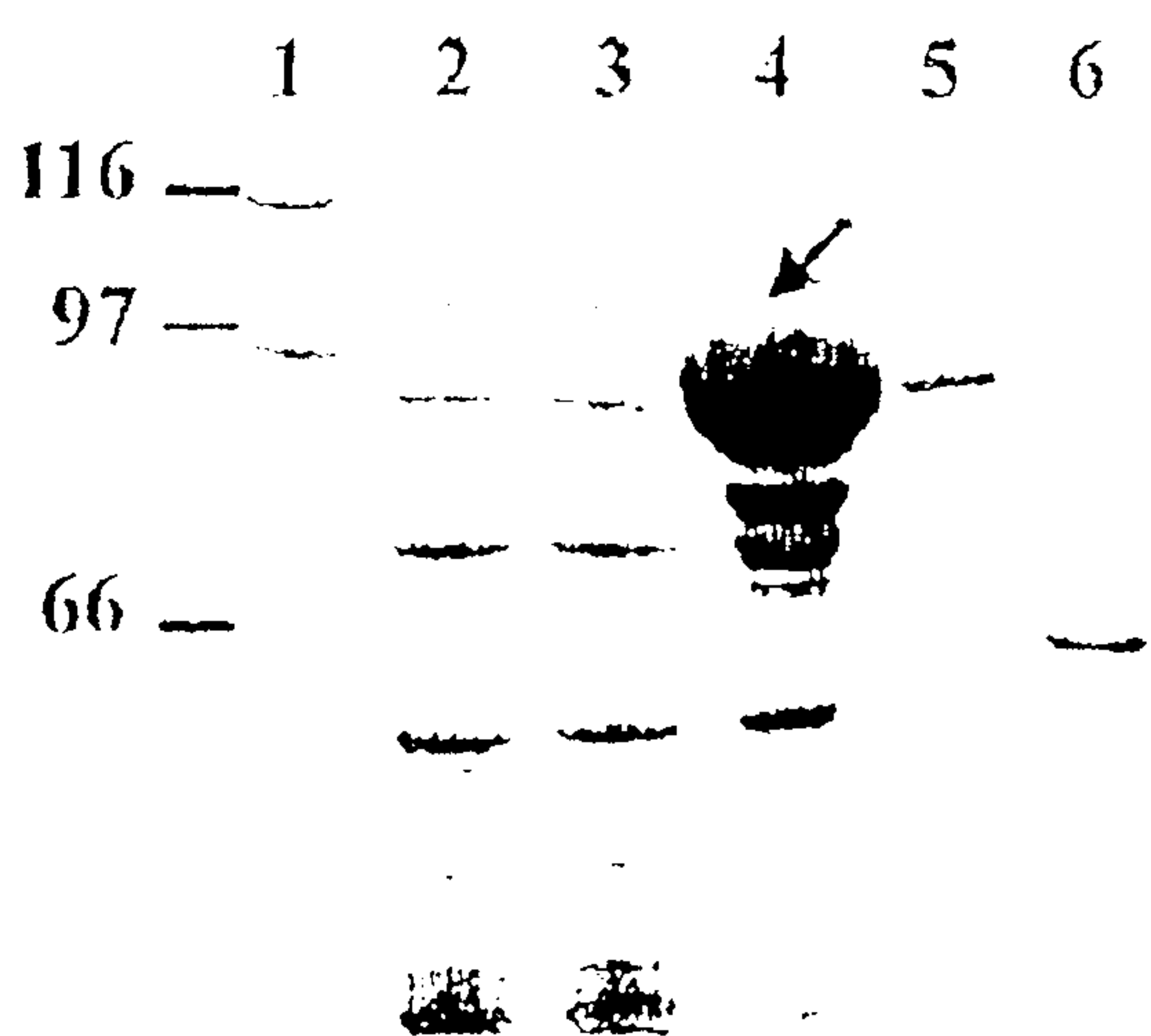
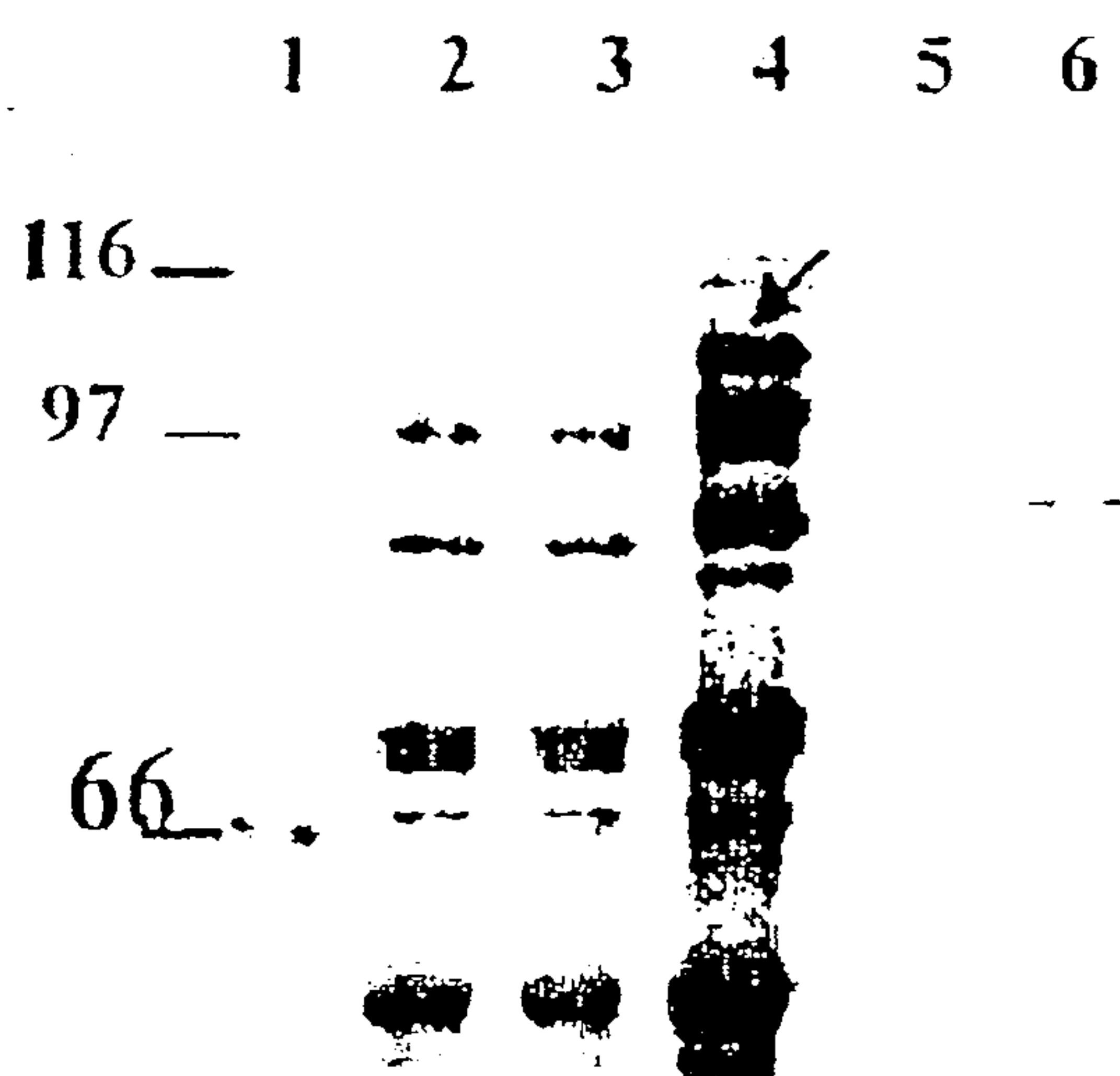
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Fig 13 B

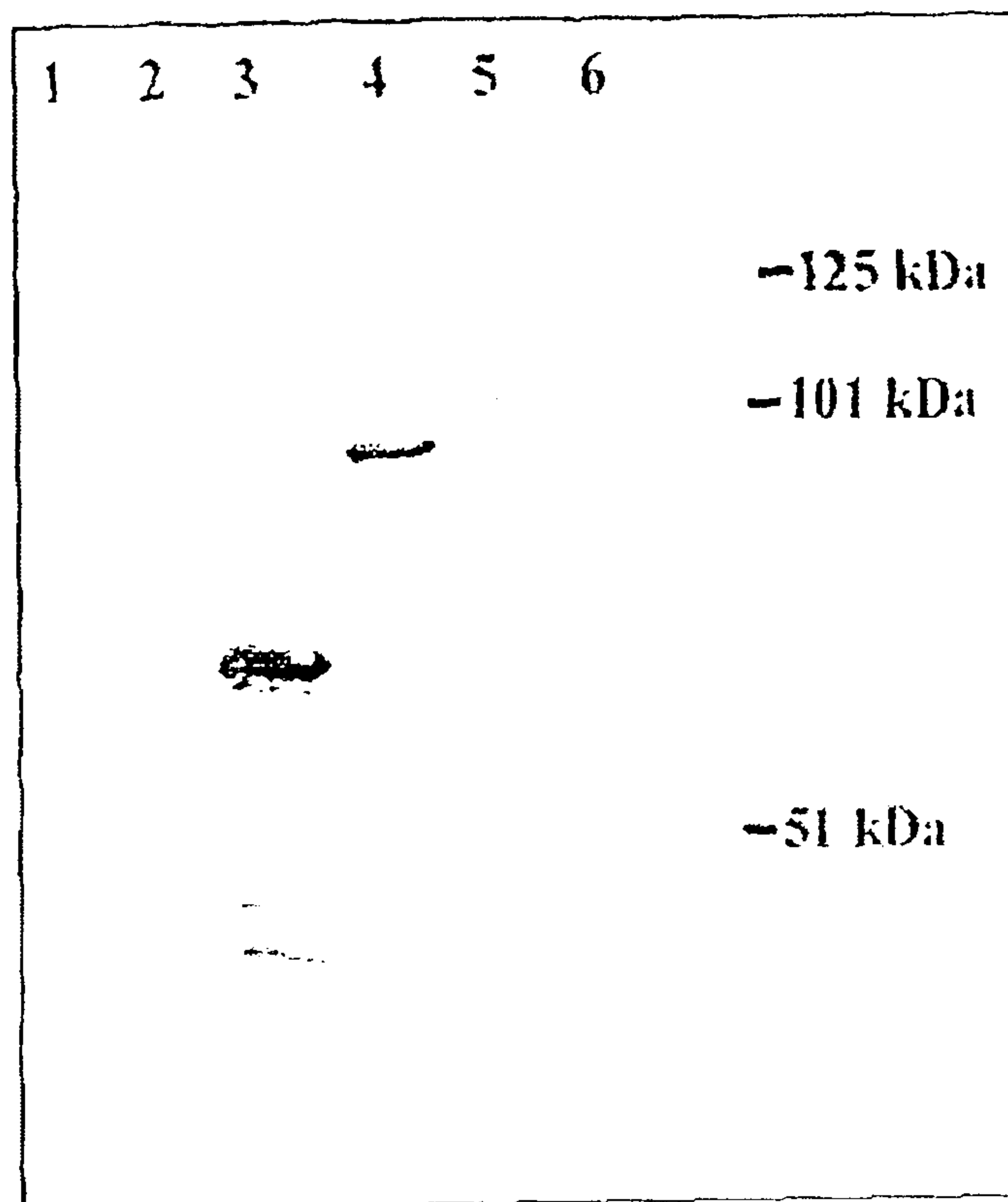
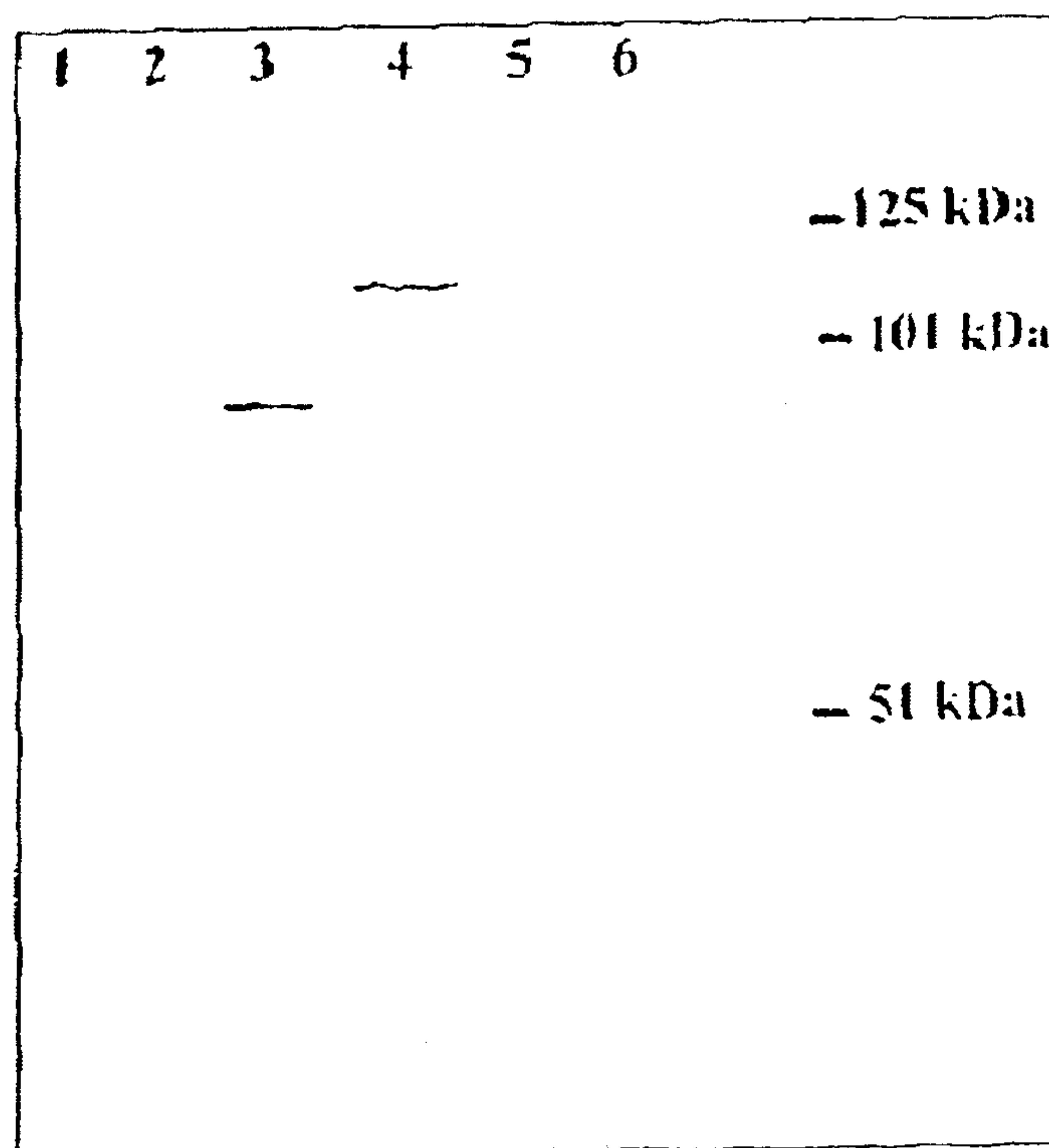
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*Fig. 14*

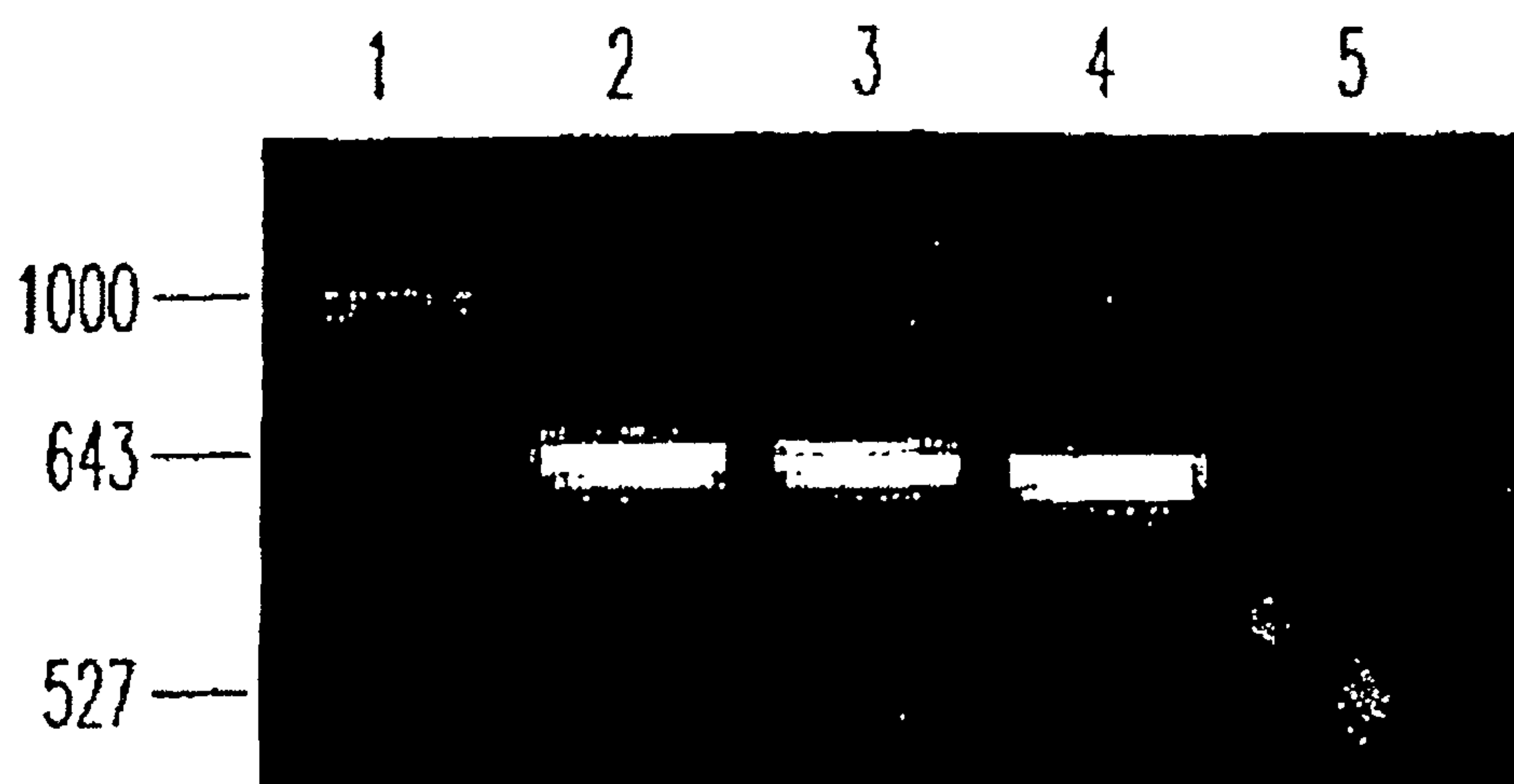
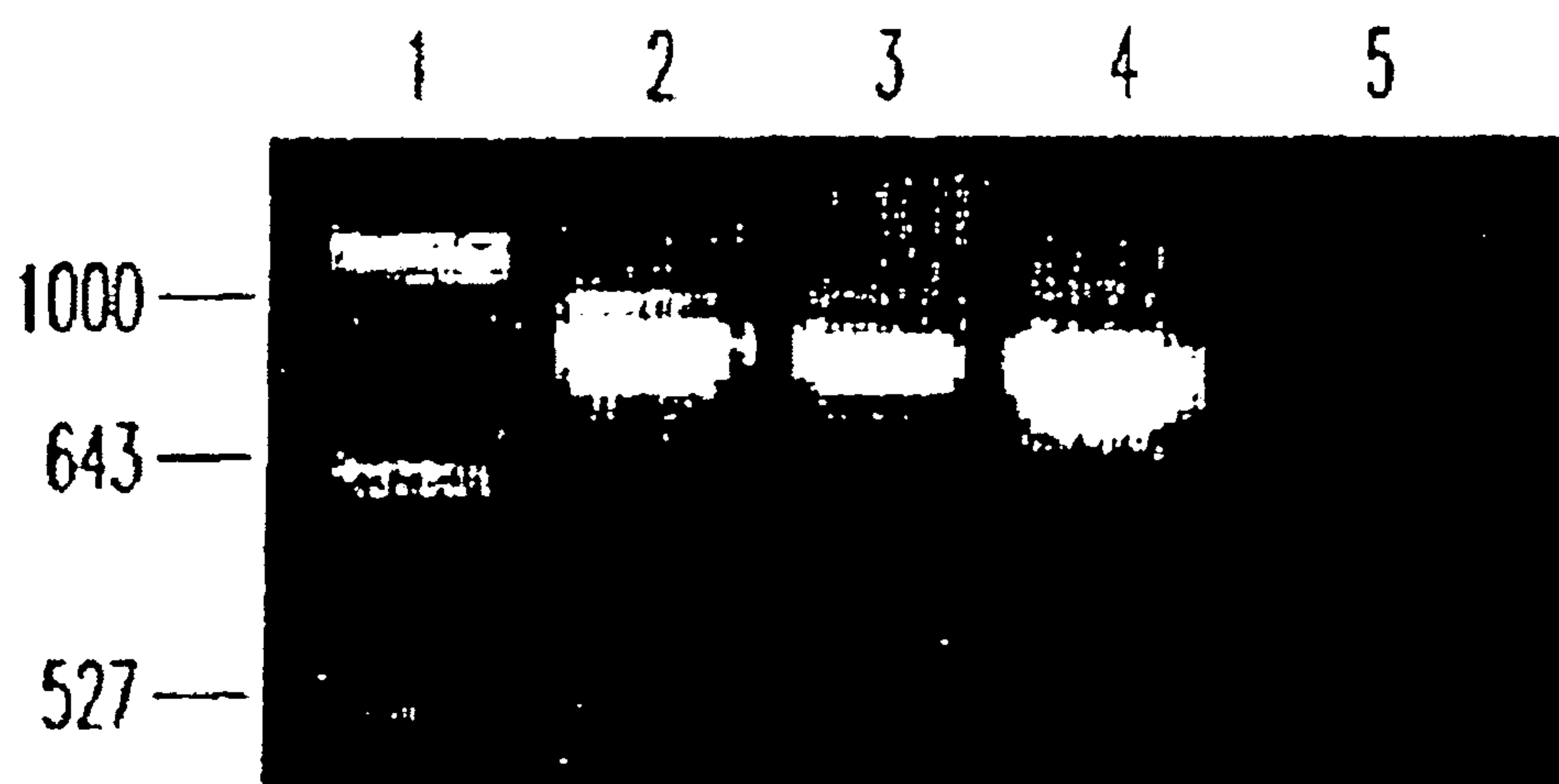
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*Fig. 15A**Fig. 15B**Fig. 15C*

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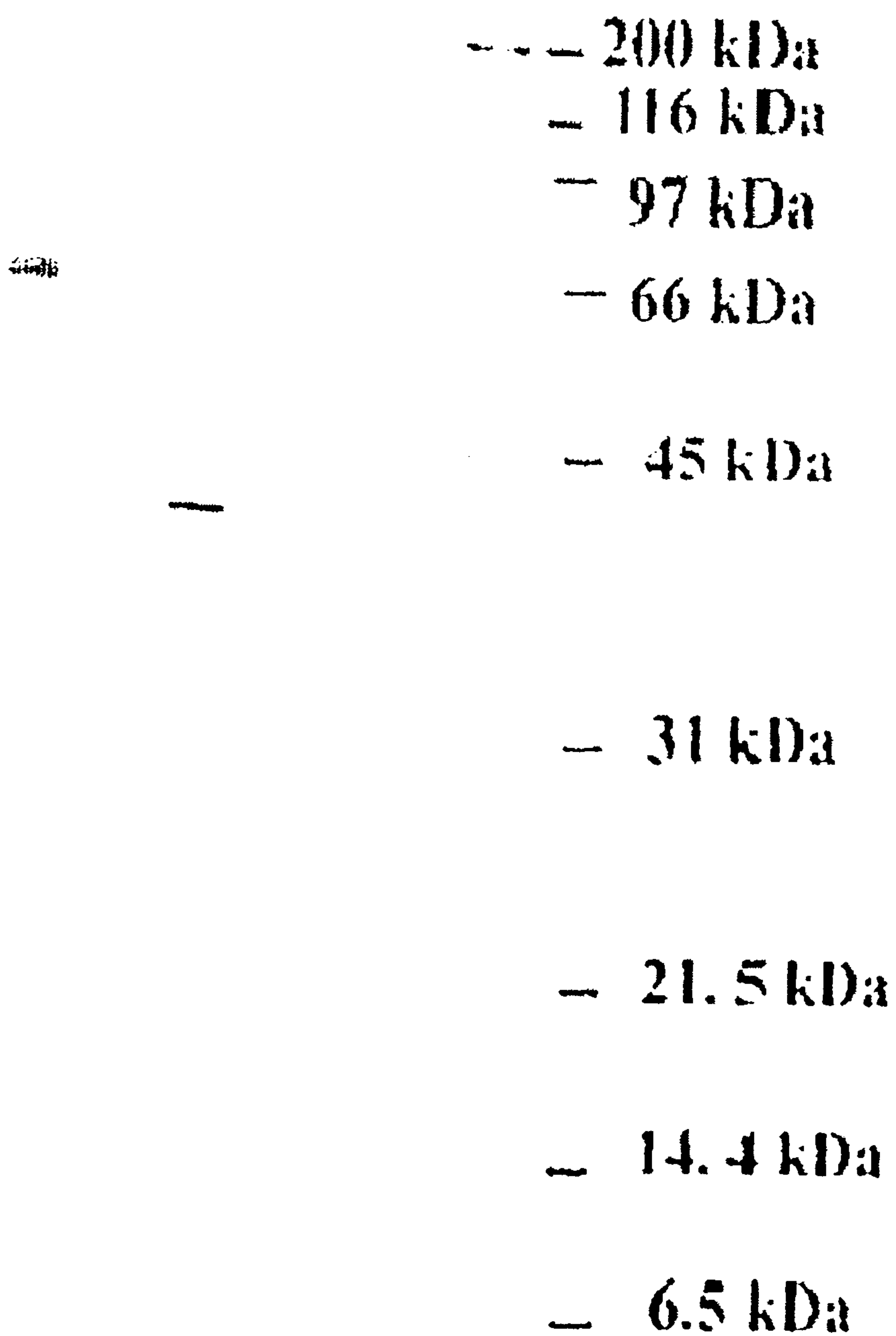
*Fig. 16A**Fig. 16B*

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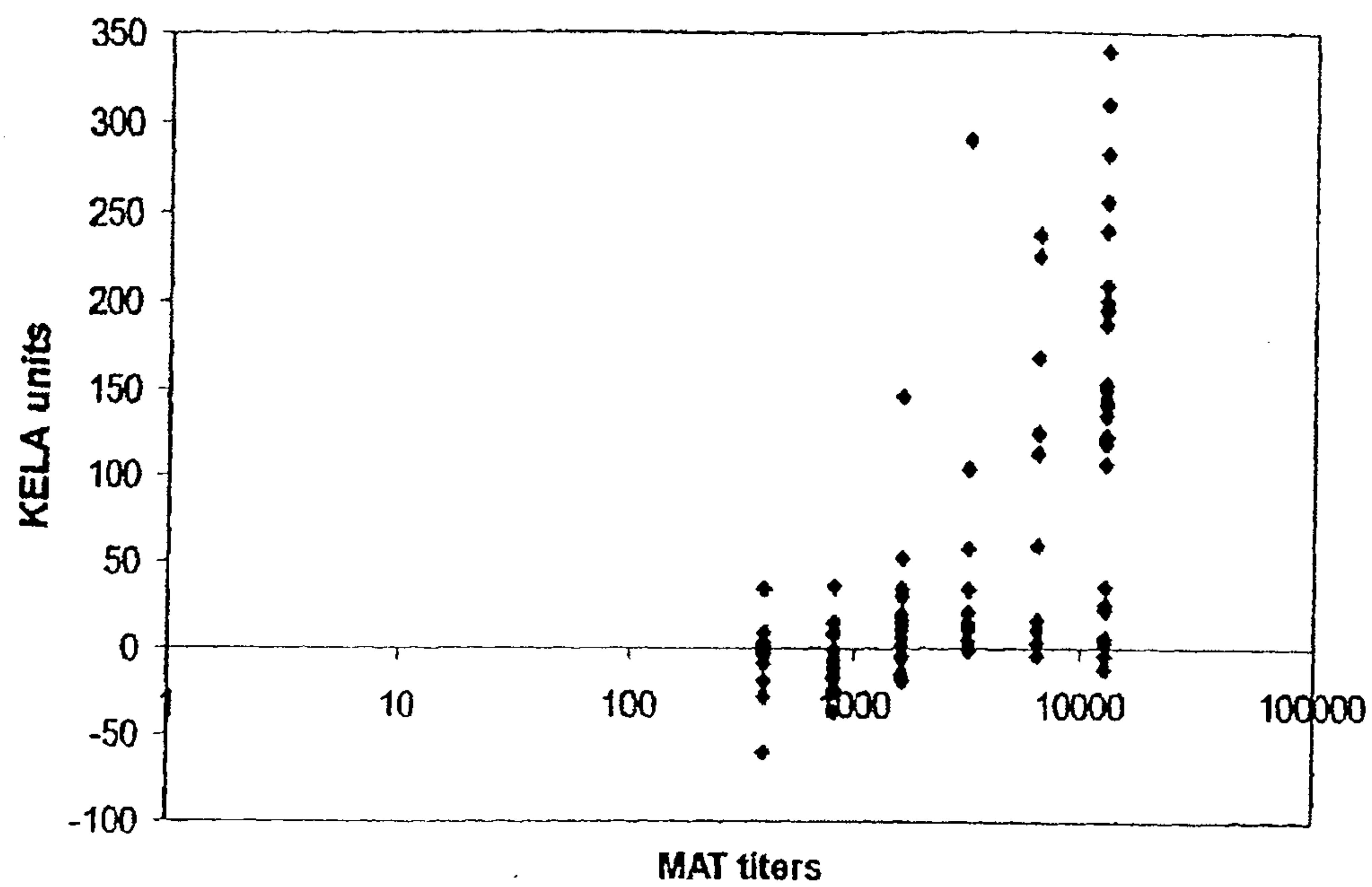
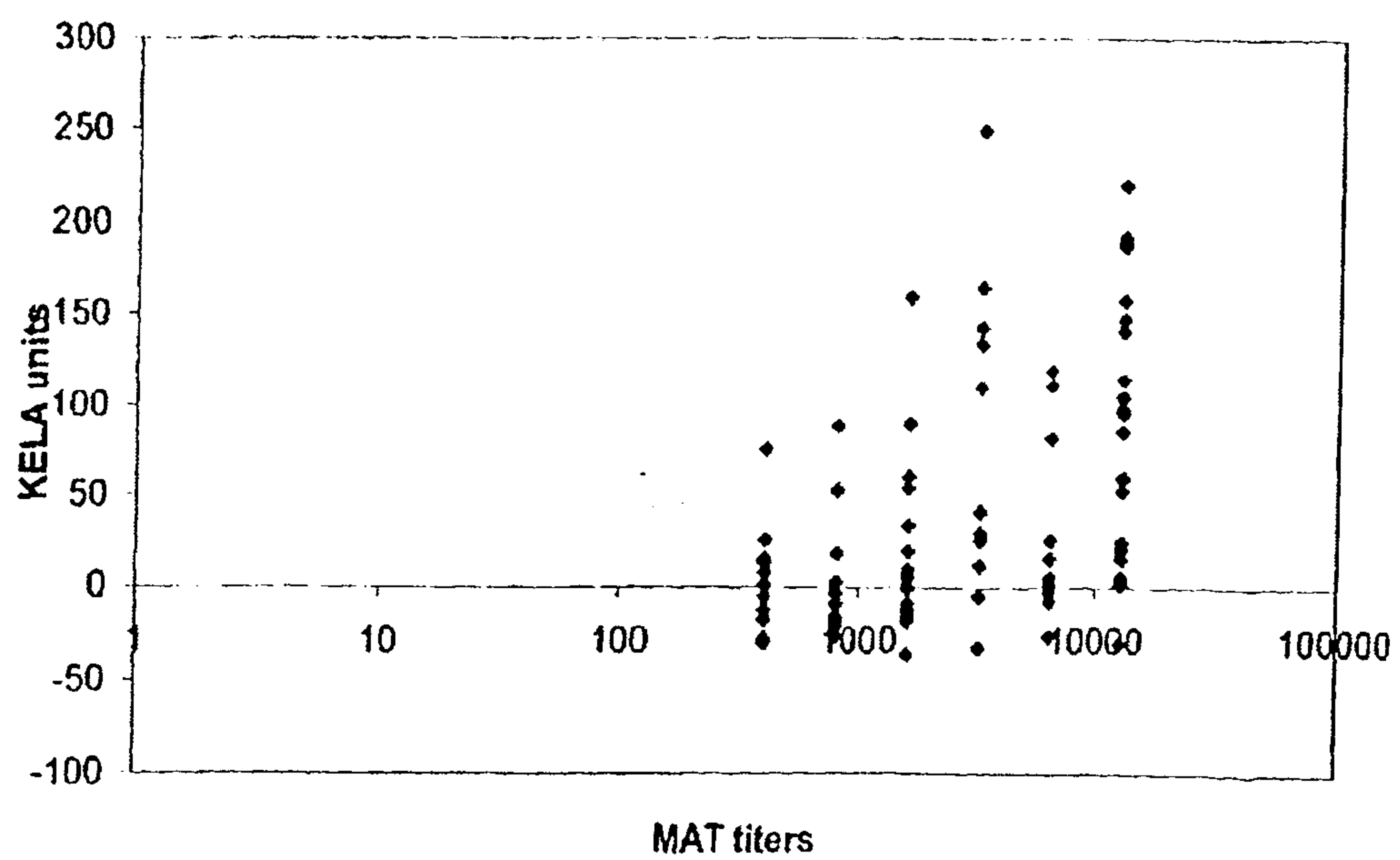
*Fig. 17A**Fig. 17B*

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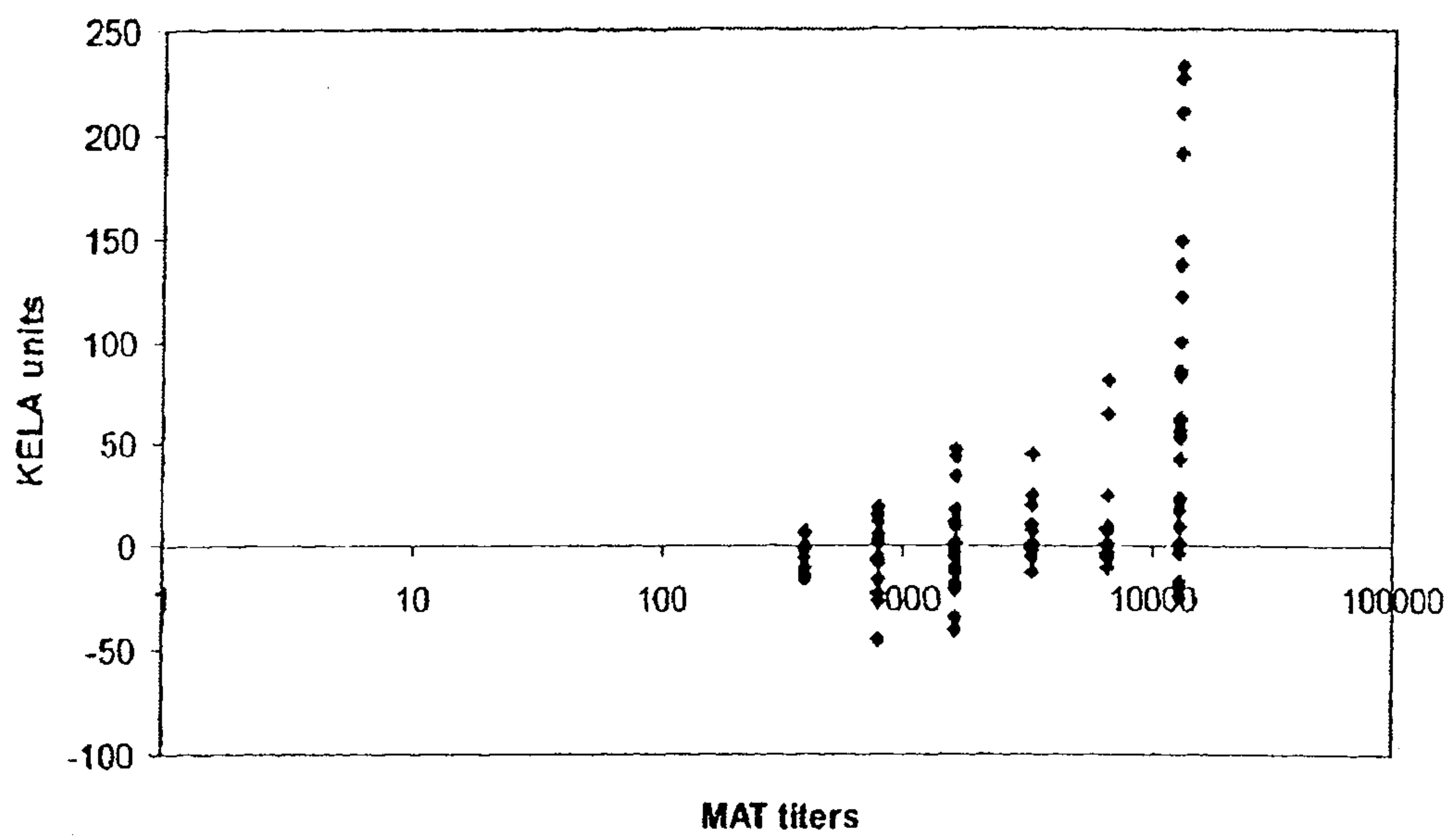
1 2 3 4 5

*Fig. 18*

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*Fig. 19A**Fig. 19B*

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*Fig. 19C'*

1 2 3 4 5

—198

—113

—93

—48

—35