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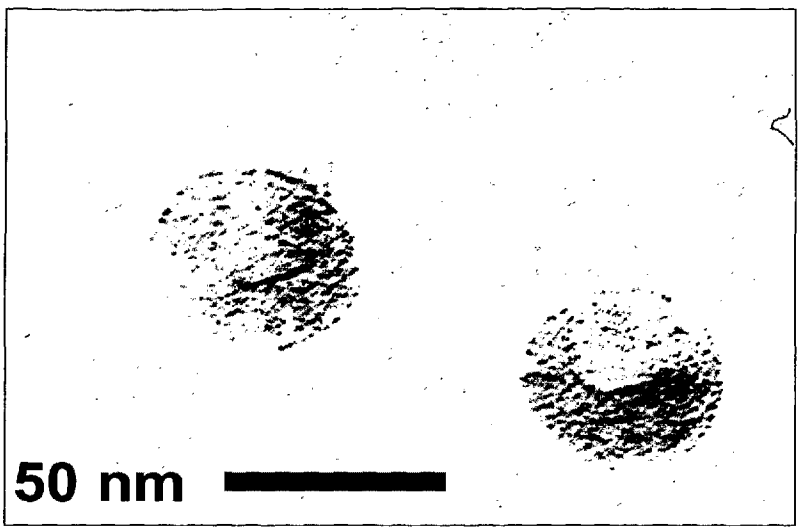
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(72) Inventeurs/Inventors:
GERKE, CHRISTIANE, IT;
BERLANDA SCORZA, FRANCESCO, IT;
SAUL, ALLAN, IT;
MAGGIORE, LUANA, IT

(73) Propriétaire/Owner:
GSK VACCINES INSTITUTE FOR GLOBAL HEALTH S.R.L., IT

(74) Agent: NORTON ROSE FULBRIGHT CANADA LLP/S.E.N.C.R.L., S.R.L.

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Hyperblebbing Shigella strains are generated by disrupting one or more components of the Tol-Pal system. The blebs from these strains are useful immunogens for vaccination. The individual proteins found in these blebs can also be used as immunogens.

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(71) Applicant *(for all designated States except US)*: **NOVARTIS VACCINES INSTITUTE FOR GLOBAL HEALTH SRL** [IT/IT]; Via Fiorentina 1, 53100 Siena (IT).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **GERKE, Christiane** [DE/IT]; Novartis Vaccines, Via Fiorentina 1, 53100 Siena (IT). **BERLANDA SCORZA, Francesco** [IT/IT]; Novartis Vaccines, Via Fiorentina 1, 53100 Siena (IT). **SAUL, Allan** [AU/IT]; Novartis Vaccines, Via Fiorentina 1, 53100 Siena (IT). **MAGGIORE, Luana** [IT/IT]; Novartis Vaccines, Via Fiorentina 1, 53100 Siena (IT).

(74) Agents: **MARSHALL, Cameron, John** et al.; Carpmaels & Ransford, One Southampton Row, London WC1B 5HA (GB).

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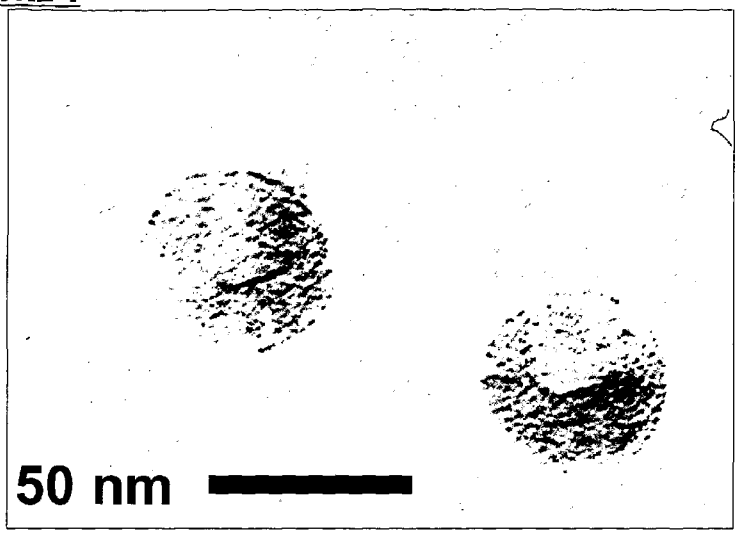
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(54) **Title**: HYPERBLEBBING SHIGELLA STRAINS

FIGURE 1



(57) **Abstract**: Hyperblebbing Shigella strains are generated by disrupting one or more components of the Tol-Pal system. The blebs from these strains are useful immunogens for vaccination. The individual proteins found in these blebs can also be used as immunogens.

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HYPERBLEBBING SHIGELLA STRAINS

TECHNICAL FIELD

This invention is in the field of immunisation against *Shigella* species.

BACKGROUND ART

Shigella are Gram-negative non-motile facultative anaerobic bacilli that fall into four serogroups: *S.dysenteriae, S.flexneri, S.boydii* and *S.sonnei.* They cause shigellosis (bacillary dysentery).

The hallmark of clinical shigellosis is an acute rectocolitis associated with fever, nausea, anorexia, dehydration, mucopurulent and bloody diarrhea, and tenesmus. *Shigella*-caused dysentery is endemic and causes millions of illness episodes in developing countries. For example, there are estimated to be 165 million cases of *Shigella* diarrhea per year, 99% of which occur in developing countries and 69% of which occur in children under five years of age. The morbidity and mortality due to shigellosis are especially high among children in developing countries.

Existing approaches to *Shigella* vaccines were reviewed in ref. 1 and have been based on live attenuated strains for oral immunisation, conjugated O saccharides for injection, proteosomes (meningococcal outer membrane vesicles with attached *Shigella* LPS) for intranasal use, invaplexes (subcellular extracts of *Shigella* including IpaB, IpaC and LPS) for intranasal use, and nuclear protein-ribosomal complexes prepared from *msbB*$^{-ve}$ strains with detoxified LPS. Although some of these vaccines have been efficacious in field trials, none protects against multiple *Shigella* serotypes.

It is an object of the invention to provide further and improved components useful in preparing *Shigella* vaccines, and in particular vaccines which can protect against multiple serotypes.

DISCLOSURE OF THE INVENTION

Shigella spontaneously release outer membrane blebs during growth due to the turgour pressure of the cell envelope. As disclosed in reference 2, release of the blebs is highly dependent on the bacterial envelope structure. The inventors have used a mutant strain of *Shigella* in which the Tol-Pal system has been disrupted to disturb the envelope structure. During normal growth these mutant strains release into their culture medium large quantities of blebs which are rich in immunogenic outer membrane proteins, and these blebs can thus be used as immunogens.

Thus the invention provides a *Shigella* bacterium which expresses no more than 4 of TolA, TolB, TolQ, TolR and Pal proteins. Thus at least one protein from the natural five-protein Tol-Pal system is absent, resulting in a bacterium which, during growth in culture medium, releases greater quantities of outer membrane blebs into the medium than the same bacterium expressing all 5 Tol-Pal proteins. Preferably TolR is not expressed, but the other four proteins may be expressed.

The invention also provides a *Shigella* bacterium which does not express a TolR protein. The invention also provides a Δ*tolR* strain of *Shigella*, such as a Δ*tolR*Δ*galU* strain.

The invention also provides a *Shigella* bacterium which expresses TolA, TolB, TolQ, TolR and Pal proteins, wherein the TolA, TolQ, TolR and/or Pal protein (a) is located in the bacterium's inner or outer membrane, and (b) includes one or more amino acid sequence mutation(s) such that, compared to the same bacterium without said mutation(s), the bacterium releases greater quantities of outer membrane blebs when growing in culture medium.

The invention also provides a *Shigella* bacterium in which one or more components of its Tol-Pal system has a modification such that, during growth in culture medium, the bacterium releases greater quantities of outer membrane blebs into the medium than the same bacterium lacking the modification, and which does not express: (i) a native *Shigella* lipopolysaccharide and/or (ii) a *Shigella* enteric toxin.

The invention also provides a method of preparing a hyperblebbing *Shigella* bacterium, comprising a step of modifying gene(s) encoding one or more components of a starting bacterium's Tol-Pal system such that the modification causes the bacterium, when grown in culture medium, to release greater quantities of outer membrane blebs into the medium than the starting bacterium, and wherein the modification involves mutating one or more of the starting bacterium's *tolA, tolB, tolQ, tolR* and/or *pal* genes. The mutating step may delete the gene. The method may also involve modification of gene(s) encoding a protein required for synthesis of the bacterium's lipopolysaccharide or an enteric toxin.

The invention also provides a bleb isolated or obtainable from a bacterium of the invention. These blebs are useful as components of *Shigella* vaccines.

The invention also provides a process for preparing *Shigella* blebs, comprising a step of separating the blebs from a culture medium comprising bacteria of the invention which have been grown under conditions which permit the release of blebs into the medium by the bacteria. Blebs prepared by this process can be used as components of *Shigella* vaccines.

The invention also provides a culture medium comprising bacteria of the invention which have been grown under conditions which permit the release of blebs into the medium by the bacteria. Blebs may be purified from this culture medium.

The invention also provides a composition comprising blebs that, during culture of bacteria of the invention, are released into the culture medium. This composition does not comprise any living and/or whole bacteria. This composition and/or its components can be used for *Shigella* vaccine preparation.

The invention also provides a composition comprising blebs, wherein the blebs are present in the filtrate obtainable after filtration through a 0.22μm filter of a culture medium in which a bacterium of the invention has been grown. This composition and/or its components can be used for *Shigella* vaccine preparation.

The invention also provides a *Shigella* bleb which includes one or more (*i.e.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59 or 60) of: (a) a protein consisting of an amino acid sequence selected from SEQ ID NOs: 8 to 67; (b) a protein comprising an amino acid sequence having at least *j*% identity to one of SEQ ID NOs: 8 to 67, where *j* is 50 or more (*e.g.* 60, 65, 70, 75, 80, 85, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99) and/or comprising a fragment of at least *n* consecutive amino acids of any one of SEQ ID NOs: 8 to 67, wherein n is 7 or more (*e.g.* 8, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90, 100, 150, 200, 250 or more). Preferred fragments comprise an epitope from one of SEQ ID NOs: 8 to 67. Other preferred fragments lack one or more amino acids (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25 or more) from the C-terminus and/or one or more amino acids (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25 or more) from the N-terminus of the SEQ ID NO: while retaining at least one epitope of the SEQ ID NO:. Other fragments omit one or more protein domains *e.g.* lacking a signal peptide, *etc.*

60 proteins have been confirmed as present within blebs of the invention and to be immunoreactive with sera prepared against the blebs. Thus the individual proteins may be used as immunogenic components in purified form, separate from the blebs. Thus the invention also provides a bleb-free immunogenic composition comprising a bleb protein comprising: (a) one or more (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59 or 60) of amino acid sequences SEQ ID NOs 8 to 67; (b) an amino acid sequence having at least *j*% identity to one of SEQ ID NOs: 8 to 67, where *j* is 50 or more (*e.g.* 60, 65, 70, 75, 80, 85, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99) and/or comprising a fragment of at least *n* consecutive amino acids of any one of SEQ ID NOs: 8 to 67, wherein n is 7 or more (*e.g.* 8, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90, 100, 150, 200, 250 or more). Preferred fragments comprise an epitope from one of SEQ ID NOs: 8 to 67, and more preferred fragments are immunogenic fragments. Other preferred fragments lack one or more amino acids (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25 or more) from the C-terminus and/or one or more amino acids (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25 or more) from the N-terminus of a SEQ ID NO: while retaining at least one epitope of the SEQ ID NO:. Other fragments omit one or more protein domains *e.g.* lacking a transmembrane domain, a signal peptide, *etc.*

The invention also provides a *Shigella* bleb which includes one or more (*i.e.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128 or 129) of: (a) a protein consisting of an amino acid sequence selected from SEQ ID NOs: 8 to 136; (b) a protein

comprising an amino acid sequence having at least *j*% identity to one of SEQ ID NOs: 8 to 136, where *j* is 50 or more (*e.g.* 60, 65, 70, 75, 80, 85, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99) and/or comprising a fragment of at least *n* consecutive amino acids of any one of SEQ ID NOs: 8 to 136, wherein n is 7 or more (*e.g.* 8, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90, 100, 150, 200, 250 or more). Preferred fragments comprise an epitope from one of SEQ ID NOs: 8 to 136. Other preferred fragments lack one or more amino acids (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25 or more) from the C-terminus and/or one or more amino acids (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25 or more) from the N-terminus of the SEQ ID NO: while retaining at least one epitope of the SEQ ID NO:. Other fragments omit one or more protein domains *e.g.* lacking a signal peptide, *etc.*

129 proteins have been confirmed as present within blebs of the invention and to be immunoreactive with sera prepared against the blebs. Thus the individual proteins may be used as immunogenic components in purified form, separate from the blebs. Thus the invention also provides a bleb-free immunogenic composition comprising a bleb protein comprising: (a) one or more (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128 or 129) of amino acid sequences SEQ ID NOs 8 to 136; (b) an amino acid sequence having at least *j*% identity to one of SEQ ID NOs: 8 to 136, where *j* is 50 or more (*e.g.* 60, 65, 70, 75, 80, 85, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99) and/or comprising a fragment of at least *n* consecutive amino acids of any one of SEQ ID NOs: 8 to 136, wherein n is 7 or more (*e.g.* 8, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90, 100, 150, 200, 250 or more). Preferred fragments comprise an epitope from one of SEQ ID NOs: 8 to 136, and more preferred fragments are immunogenic fragments. Other preferred fragments lack one or more amino acids (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25 or more) from the C-terminus and/or one or more amino acids (*e.g.* 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25 or more) from the N-terminus of a SEQ ID NO: while retaining at least one epitope of the SEQ ID NO:. Other fragments omit one or more protein domains *e.g.* lacking a transmembrane domain, a signal peptide, *etc.*

Within SEQ ID NOs: 8 to 136, a preferred subset in relation to *S.flexneri* is the SEQ ID NOs: listed in "Subset 1" beneath Table 1. Within SEQ ID NOs: 8 to 136, a preferred subset in relation to *S.sonnei* is the SEQ ID NOs: listed in "Subset 2" beneath Table 1

The Tol-Pal system

Like many Gram-negative bacteria, the *Shigella* naturally possess a Tol-Pal system which is made up of TolA, TolB, TolQ, TolR and Pal proteins. According to the invention, the natural Tol-Pal system is disrupted, thereby causing the bacterium to release greater quantities of outer membrane blebs into its culture medium during bacterial replication. Various disruptions can be made.

In some embodiments, at least one of the five Tol-Pal proteins is removed *e.g.* by deletion or inactivation of the gene encoding the protein. Thus the bacterium may express 0, 1, 2, 3 or 4 of TolA, TolB, TolQ, TolR and Pal proteins. Removal of one of the five proteins can suffice, in which case the bacterium expresses only 4 of these proteins. Preferably the TolR protein is removed *e.g.* by inactivation of a starting strain's *tolR* gene. Thus the bacterium may be $tolA^+$ $tolB^+$ $tolQ^+$ $TolR^-$ Pal^+.

In some embodiments, the bacterium expresses all five Tol-Pal proteins, but at least one is mutated to cause hyperblebbing. For instance, the TolA, TolQ, TolR and/or Pal protein may be mutated such that the protein retains its membrane localisation but its interactions with other members of the Tol-Pal system are disrupted. The bacterium will thus retain TolA, TolQ and TolR as transmembrane proteins in the inner membrane, and Pal protein as a periplasm-facing lipoprotein in the outer membrane, but at least one of the TolA, TolQ, TolR and/or Pal proteins is mutated.

Examples of wild-type *Shigella* amino acid sequences of the TolA, TolB, TolQ, TolR and Pal proteins are given in the sequence listing as SEQ ID NOs: 1 to 5.

The Shigella bacterium

The invention can be used with any of serogroups *S.dysenteriae, S.flexneri, S.boydii* and *S.sonnei.*

In addition to having a disrupted Tol-Pal system, thereby causing the bacterium to release greater quantities of outer membrane blebs into its culture medium during bacterial replication, a *Shigella* of the invention can advantageously include one or more further changes relative to a wild-type strain. These changes can be used in particular to remove components from the bacterium which would be toxic or undesirable in a human vaccine.

For example, a bacterium may not express native *Shigella* lipopolysaccharide (LPS), thereby reducing endotoxic activity. Various modifications can be made to prevent synthesis of native LPS, and these may disrupt the native lipid A structure, the oligosaccharide core, or the outer O antigen. For example, reference 3 reports LPS mutants caused by inactivation of the *rfe* and *galU* genes, and reference 4 reports LPS mutants caused by inactivation of *yihE, galE, galK, galM* and *galT.* Similarly, reference 5 reports defective LPS due to mutations in *rfc*, *rfaL*, or *galU.* Reference 6 reports LPS mutants caused by inactivation of *msbB1* and *msbB2*, reducing acylation in lipid A. As shown herein, another LPS mutant with reduced lipid A acylation can be generated by inactivation of *htrB* [7,8].

Absence of O antigen in the LPS is preferred, thereby avoiding serotype-specific responses. In *S.sonnei* the O antigen is absent when the virulence plasmid is removed (see below). The *galU* gene codes for uridine diphosphoglucose (UDP-glucose) pyrophosphorylase and its inactivation results in synthesis of LPS with no attached O antigen. Inactivation of *galU* is useful for providing a *Shigella* without uridine diphosphoglucose pyrophosphorylase activity. Inactivation of *rfbF* and/or *rfbG* genes can be used to provide a *Shigella* without rhamnosyl transferase activity. Inactivation of *rfc* can be

used to provide a *Shigella* without O antigen polymerase activity. Inactivation of all three of *rfbF*, *rfbG* and *rfc* can provide a useful strain.

Absence of hexa-acylated lipid A in the LPS is preferred. Loss of the virulence plasmid (see below) automatically leads to loss of the *msbB2* gene, and the chromosomal *msbB1* gene can be inactivated, thereby removing myristoyl transferase activity and providing a penta-acylated lipid A in the LPS. Inactivation of the HtrB lauroyl transferase can provide *Shigella* with mainly tetra-acylated lipid A. Preferred strains have penta- or tetra-acylated LPS.

Preferred strains are inactivated for both *galU* and *msbB1* and also lack the virulence plasmid, thereby providing a strain whose LPS is penta-acylated and lacks attached O antigen.

Some useful strains have penta- or tetra-acylated LPS which includes attached O antigen. More generally, though, preferred strains have penta- or tetra-acylated LPS which lacks attached O antigen. A *S.flexneri* strain with *tolR, rfbG* and *htrB* knockouts (and, optionally, *rfbF* and/or *rfc* inactivation) is useful. A useful *S.sonnei* strain has a *tolR* mutation and lacks a virulence plasmid.

A bacterium may not express an enteric toxin. For instance, a *S.flexneri* strain (particularly a 2a strain) may not express all of the subunits of *Shigella* enterotoxin 1 (ShET-1) *e.g.* the *set1A* and/or *set1B* genes can be inactivated. A *S.dysenteriae* strain may not express both subunits of Shiga toxin *e.g.* one or both of the *stxA* and/or *stxB* genes can be inactivated. A *Shigella*, particularly a *S.sonnei* or *S.flexneri,* may not express enterotoxin 2 (ShET-2) *e.g.* the *ospD3* gene may be inactivated, or the virulence plasmid may be absent. Preferred strains encode none of ShET-1, ShET-2 and Shiga toxin.

Shigella bacteria of the invention can be prepared conveniently from wild-type or other starting strains using conventional techniques of mutagenesis *e.g.* see references 9 to 11. The lambda red recombination system is particularly useful with *Shigella*. Inactivation of a gene can be achieved in various ways *e.g.* by deletion or mutation in its promoter, by deletion or mutation of its start codon, by introduction of a premature stop codon, by deletion of the complete coding region, by knockout, *etc.* Isogenic knockout mutants are preferred. In the resulting *Shigella* bacterium, mRNA encoding the desired gene is absent and/or its translation is inhibited (*e.g.* to less than 1% of wild-type levels).

A *Shigella* bacterium of the invention may contain a marker gene in place of the inactivated gene *e.g* an antibiotic resistance marker. This can be achieved using homologous recombination. Preferably, though, unmarked deletions (*i.e.* deletion without introduction of a marker gene) are used.

Virulent *Shigella* strains possess a 220kb plasmid that mediates virulence properties. This "virulence plasmid" has been shown to encode the genes for several aspects of Shigella virulence, including adhesins for target epithelial cells, the invasion plasmid antigens, *virF, virG, etc.* A *Shigella* of the invention may possess a virulence plasmid but, preferably, it does not possess a virulence plasmid. Absence of the plasmid can stabilise the strain during industrial culture, attenuate the strain by removing virulence factors (thereby increasing safety of manufacture), disrupt the lipopolysaccharide

(the biosynthesis genes for the O antigen are on the plasmid in *S.sonnei*), avoid the presence of the ShET-2 enterotoxin (encoded by the *ospD3* or *sen* gene on the plasmid), and avoid the presence of *msbB2* which is a second copy of the *msbB* gene responsible for acylation of lipid A.

A *Shigella* of the invention may express one or more heterologous proteins *e.g.* proteins which are not naturally found in *Shigella*. If the heterologous protein is an outer membrane protein then blebs from the strain can be used as a delivery system for presenting non-*Shigella* antigens to the immune system.

Culture conditions for growing *Shigella* are well known in the art *e.g.* see references 12 to 14. For example, they may be grown using an organic nitrogen source (such as amino acid mixtures *e.g.* containing Ala, Arg, Asn, Asp; casamino acids may be used), glycerol as a carbon source, *etc.* Inclusion of L-aspartic acid in the medium is particularly useful and may function as both a nitrogen and carbon source.

Advantageously, *Shigella* of the invention may be grown under iron-limiting conditions as this has been shown to up-regulate iron-regulated proteins which are immunogenic and highly-conserved among *Shigella* spp. For instance, the bacteria may be grown in the presence of a compound such as desferal or 2,2'-dipyridyl or 8-hydroxyquinoline. Under these conditions the bacterium may increase expression of proteins such as the FepA outer membrane receptor, the colicin I receptor (CirA), and/or the ferric siderophore receptor (FhuA).

Blebs and hyperblebbing

Shigella bacteria of the invention are, relative to their corresponding wild-type strains, hyperblebbing *i.e.* they release into their culture medium larger quantities of blebs than the wild-type strain. These blebs are useful as components of *Shigella* vaccines.

The blebs typically have a diameter of 35-120nm by electron microscopy *e.g.* 50nm diameter.

The blebs are released spontaneously during bacterial growth and can be purified from the culture medium. The purification ideally involves separating the blebs from living and/or intact *Shigella* bacteria *e.g.* by size-based filtration using a filter, such as a 0.22μm filter, which allows the blebs to pass through but which does not allow intact bacteria to pass through, or by using low speed centrifugation to pellet cells while leaving blebs in suspension.

Thus, unlike the culture medium, bleb-containing compositions of the invention will generally be substantially free from whole bacteria, whether living or dead. The size of the blebs means that they can readily be separated from whole bacteria by filtration *e.g.* as typically used for filter sterilisation. Although blebs will pass through a standard 0.22μm filters, these can rapidly become clogged by other material, and so it may be useful to perform sequential steps of filter sterilisation through a series of filters of decreasing pore size before using a 0.22μm filter. Examples of preceding filters would be those with pore size of 0.8μm, 0.45μm, *etc.*

Separation of spontaneously-released blebs from the culture medium is more convenient than methods which involve deliberate disruption of the outer membrane (*e.g.* by detergent treatment or sonication) to cause outer membrane vesicles to form. Moreover, they are substantially free from inner membrane and cytoplasmic contamination.

Blebs of the invention contain lipids and proteins. The protein content of the blebs has been analysed, and they include the proteins listed in Table 1 and discussed below.

Shigella outer membrane proteins

Table 1 lists the GenBank name and GI number for 129 proteins which were detected in *Shigella* blebs of the invention. These 127 proteins may be used as immunogenic components in purified form, separate from blebs. A preferred subset of the 129 is the first 60 in the list ("Subset 3").

Polypeptides can be prepared by various means *e.g.* by chemical synthesis (at least in part), by digesting longer polypeptides using proteases, by translation from RNA, by purification from cell culture (*e.g.* from recombinant expression or from *Shigella* culture). *etc.* Heterologous expression in an *E.coli* host is a preferred expression route.

Polypeptides of the invention may be attached or immobilised to a solid support. Polypeptides of the invention may comprise a detectable label *e.g.* a radioactive label, a fluorescent label, or a biotin label. This is particularly useful in immunoassay techniques.

Polypeptides can take various forms (*e.g.* native, fusions, glycosylated, non-glycosylated, lipidated, disulfide bridges, *etc.*). Polypeptides are preferably *Shigella* polypeptides.

Polypeptides are preferably prepared in substantially pure or substantially isolated form (*i.e.* substantially free from other *Shigella* or host cell polypeptides) or substantially isolated form. In general, the polypeptides are provided in a non-naturally occurring environment *e.g.* they are separated from their naturally-occurring environment. In certain embodiments, the subject polypeptide is present in a composition that is enriched for the polypeptide as compared to a control. As such, purified polypeptide is provided, whereby purified is meant that the polypeptide is present in a composition that is substantially free of other expressed polypeptides, where by substantially free is meant that less than 50%, usually less than 30% and more usually less than 10% of the composition is made up of other expressed polypeptides.

The term "polypeptide" refers to amino acid polymers of any length. The polymer may be linear or branched, it may comprise modified amino acids, and it may be interrupted by non-amino acids. The terms also encompass an amino acid polymer that has been modified naturally or by intervention; for example, disulfide bond formation, glycosylation, lipidation, acetylation, phosphorylation, or any other manipulation or modification, such as conjugation with a labeling component. Also included within the definition are, for example, polypeptides containing one or more analogs of an amino acid

(including, for example, unnatural amino acids, *etc.*), as well as other modifications known in the art. Polypeptides can occur as single chains or associated chains.

Pharmaceutical compositions

The invention provides a pharmaceutical composition comprising (a) blebs of the invention and (b) a pharmaceutically acceptable carrier. The invention also provides a process for preparing such a composition, comprising the step of admixing blebs of the invention with a pharmaceutically acceptable carrier.

The invention also provides a pharmaceutical composition comprising (a) the bleb-free immunogenic composition defined above and (b) a pharmaceutically acceptable carrier.

The immunogenic composition may include a pharmaceutically acceptable carrier, which can be any substance that does not itself induce the production of antibodies harmful to the patient receiving the composition, and which can be administered without undue toxicity. Pharmaceutically acceptable carriers can include liquids such as water, saline, glycerol and ethanol. Auxiliary substances, such as wetting or emulsifying agents, pH buffering substances, and the like, can also be present in such vehicles. A thorough discussion of suitable carriers is available in ref. 15.

Shigella infections can affect various areas of the body and so the compositions of the invention may be prepared in various forms. For example, the compositions may be prepared as injectables, either as liquid solutions or suspensions. Solid forms suitable for solution in, or suspension in, liquid vehicles prior to injection can also be prepared. The composition may be prepared for topical administration *e.g.* as an ointment, cream or powder. The composition be prepared for oral administration *e.g.* as a tablet or capsule, or as a syrup (optionally flavoured). The composition may be prepared for pulmonary administration *e.g.* as an inhaler, using a fine powder or a spray. The composition may be prepared as a suppository or pessary. The composition may be prepared for nasal, aural or ocular administration *e.g.* as drops.

The composition is preferably sterile. It is preferably pyrogen-free. It is preferably buffered *e.g.* at between pH 6 and pH 8, generally around pH 7. Compositions of the invention may be isotonic with respect to humans.

Immunogenic compositions comprise an immunologically effective amount of immunogen, as well as any other of other specified components, as needed. By 'immunologically effective amount', it is meant that the administration of that amount to an individual, either in a single dose or as part of a series, is effective for treatment or prevention. This amount varies depending upon the health and physical condition of the individual to be treated, age, the taxonomic group of individual to be treated (*e.g.* non-human primate, primate, *etc.*), the capacity of the individual's immune system to synthesise antibodies, the degree of protection desired, the formulation of the vaccine, the treating doctor's

assessment of the medical situation, and other relevant factors. It is expected that the amount will fall in a relatively broad range that can be determined through routine trials.

Previous work with vesicle vaccines (*e.g.* for meningococcus) offers pharmaceutical, posological and formulation guidance for administering blebs. The concentration of blebs in compositions of the invention will generally be between 10 and 500 μg/ml, preferably between 25 and 200μg/ml, and more preferably about 50μg/ml or about 100μg/ml (expressed in terms of total protein in the blebs). A dosage volume of 0.5ml is typical for injection.

The composition may be administered in conjunction with other immunoregulatory agents.

Adjuvants which may be used in compositions of the invention (particularly in bleb-free compositions) include, but are not limited to:

A. Mineral-containing compositions

Mineral containing compositions suitable for use as adjuvants in the invention include mineral salts, such as aluminium salts and calcium salts. The invention includes mineral salts such as hydroxides (*e.g.* oxyhydroxides), phosphates (*e.g.* hydroxyphosphates, orthophosphates), sulphates, *etc.* [*e.g.* see chapters 8 & 9 of ref. 19], or mixtures of different mineral compounds, with the compounds taking any suitable form (*e.g.* gel, crystalline, amorphous, *etc.*), and with adsorption being preferred. The mineral containing compositions may also be formulated as a particle of metal salt.

The adjuvants known as "aluminium hydroxide" are typically aluminium oxyhydroxide salts, which are usually at least partially crystalline. Aluminium oxyhydroxide, which can be represented by the formula AlO(OH), can be distinguished from other aluminium compounds, such as aluminium hydroxide $Al(OH)_3$, by infrared (IR) spectroscopy, in particular by the presence of an adsorption band at 1070cm^{-1} and a strong shoulder at 3090–3100cm^{-1} [chapter 9 of ref. 19]. The degree of crystallinity of an aluminium hydroxide adjuvant is reflected by the width of the diffraction band at half height (WHH), with poorly-crystalline particles showing greater line broadening due to smaller crystallite sizes. The surface area increases as WHH increases, and adjuvants with higher WHH values have been seen to have greater capacity for antigen adsorption. A fibrous morphology (*e.g.* as seen in transmission electron micrographs) is typical for aluminium hydroxide adjuvants. The pI of aluminium hydroxide adjuvants is typically about 11 *i.e.* the adjuvant itself has a positive surface charge at physiological pH. Adsorptive capacities of between 1.8-2.6 mg protein per mg Al^{+++} at pH 7.4 have been reported for aluminium hydroxide adjuvants.

The adjuvants known as "aluminium phosphate" are typically aluminium hydroxyphosphates, often also containing a small amount of sulfate (*i.e.* aluminium hydroxyphosphate sulfate). They may be obtained by precipitation, and the reaction conditions and concentrations during precipitation influence the degree of substitution of phosphate for hydroxyl in the salt. Hydroxyphosphates generally have a PO_4/Al molar ratio between 0.3 and 1.2. Hydroxyphosphates can be distinguished

from strict $AlPO_4$ by the presence of hydroxyl groups. For example, an IR spectrum band at 3164cm^{-1} (*e.g.* at 200°C) indicates the presence of structural hydroxyls [ch. 9 of ref. 19].

The PO_4/Al^{3+} molar ratio of an aluminium phosphate adjuvant will generally be between 0.3 and 1.2, preferably between 0.8 and 1.2, and more preferably 0.95±0.1. The aluminium phosphate will generally be amorphous, particularly for hydroxyphosphate salts. A typical adjuvant is amorphous aluminium hydroxyphosphate with PO_4/Al molar ratio between 0.84 and 0.92, included at 0.6mg Al^{3+}/ml. The aluminium phosphate will generally be particulate (*e.g.* plate-like morphology as seen in transmission electron micrographs). Typical diameters of the particles are in the range 0.5-20μm (*e.g.* about 5-10μm) after any antigen adsorption. Adsorptive capacities of between 0.7-1.5 mg protein per mg Al^{+++} at pH 7.4 have been reported for aluminium phosphate adjuvants.

The point of zero charge (PZC) of aluminium phosphate is inversely related to the degree of substitution of phosphate for hydroxyl, and this degree of substitution can vary depending on reaction conditions and concentration of reactants used for preparing the salt by precipitation. PZC is also altered by changing the concentration of free phosphate ions in solution (more phosphate = more acidic PZC) or by adding a buffer such as a histidine buffer (makes PZC more basic). Aluminium phosphates used according to the invention will generally have a PZC of between 4.0 and 7.0, more preferably between 5.0 and 6.5 *e.g.* about 5.7.

Suspensions of aluminium salts used to prepare compositions of the invention may contain a buffer (*e.g.* a phosphate or a histidine or a Tris buffer), but this is not always necessary. The suspensions are preferably sterile and pyrogen-free. A suspension may include free aqueous phosphate ions *e.g.* present at a concentration between 1.0 and 20 mM, preferably between 5 and 15 mM, and more preferably about 10 mM. The suspensions may also comprise sodium chloride.

In one embodiment, an adjuvant component includes a mixture of both an aluminium hydroxide and an aluminium phosphate. In this case there may be more aluminium phosphate than hydroxide *e.g.* a weight ratio of at least 2:1 *e.g.* ≥5:1, ≥6:1, ≥7:1, ≥8:1, ≥9:1, *etc.*

The concentration of Al^{+++} in a composition for administration to a patient is preferably less than 10mg/ml *e.g.* ≤5 mg/ml, ≤4 mg/ml, ≤3 mg/ml, ≤2 mg/ml, ≤1 mg/ml, *etc.* A preferred range is between 0.3 and 1mg/ml. A maximum of <0.85mg/dose is preferred.

B. Oil Emulsions

Oil emulsion compositions suitable for use as adjuvants in the invention include squalene-water emulsions, such as MF59 [Chapter 10 of ref. 19; see also ref. 16] (5% Squalene, 0.5% Tween 80, and 0.5% Span 85, formulated into submicron particles using a microfluidizer). Complete Freund's adjuvant (CFA) and incomplete Freund's adjuvant (IFA) may also be used.

Various suitable oin-in-water emulsions are known, and they typically include at least one oil and at least one surfactant, with the oil(s) and surfactant(s) being biodegradable (metabolisable) and

biocompatible. The oil droplets in the emulsion are generally less than 5μm in diameter, and advantageously the emulsion comprises oil droplets with a sub-micron diameter, with these small sizes being achieved with a microfluidiser to provide stable emulsions. Droplets with a size less than 220nm are preferred as they can be subjected to filter sterilization.

The invention can be used with oils such as those from an animal (such as fish) or vegetable source. Sources for vegetable oils include nuts, seeds and grains. Peanut oil, soybean oil, coconut oil, and olive oil, the most commonly available, exemplify the nut oils. Jojoba oil can be used *e.g.* obtained from the jojoba bean. Seed oils include safflower oil, cottonseed oil, sunflower seed oil, sesame seed oil and the like. In the grain group, corn oil is the most readily available, but the oil of other cereal grains such as wheat, oats, rye, rice, teff, triticale and the like may also be used. 6-10 carbon fatty acid esters of glycerol and 1,2-propanediol, while not occurring naturally in seed oils, may be prepared by hydrolysis, separation and esterification of the appropriate materials starting from the nut and seed oils. Fats and oils from mammalian milk are metabolizable and may therefore be used in the practice of this invention. The procedures for separation, purification, saponification and other means necessary for obtaining pure oils from animal sources are well known in the art. Most fish contain metabolizable oils which may be readily recovered. For example, cod liver oil, shark liver oils, and whale oil such as spermaceti exemplify several of the fish oils which may be used herein. A number of branched chain oils are synthesized biochemically in 5-carbon isoprene units and are generally referred to as terpenoids. Shark liver oil contains a branched, unsaturated terpenoid known as squalene, 2,6,10,15,19,23-hexamethyl-2,6,10,14,18,22-tetracosahexaene. Other preferred oils are the tocopherols (see below). Oil in water emulsions comprising sqlauene are particularly preferred. Mixtures of oils can be used.

Surfactants can be classified by their 'HLB' (hydrophile/lipophile balance). Preferred surfactants of the invention have a HLB of at least 10, preferably at least 15, and more preferably at least 16. The invention can be used with surfactants including, but not limited to: the polyoxyethylene sorbitan esters surfactants (commonly referred to as the Tweens), especially polysorbate 20 and polysorbate 80; copolymers of ethylene oxide (EO), propylene oxide (PO), and/or butylene oxide (BO), sold under the DOWFAX™ tradename, such as linear EO/PO block copolymers; octoxynols, which can vary in the number of repeating ethoxy (oxy-1,2-ethanediyl) groups, with octoxynol-9 (Triton X-100, or t-octylphenoxypolyethoxyethanol) being of particular interest; (octylphenoxy)polyethoxyethanol (IGEPAL CA-630/NP-40); phospholipids such as phosphatidylcholine (lecithin); polyoxyethylene fatty ethers derived from lauryl, cetyl, stearyl and oleyl alcohols (known as Brij surfactants), such as triethyleneglycol monolauryl ether (Brij 30); and sorbitan esters (commonly known as the SPANs), such as sorbitan trioleate (Span 85) and sorbitan monolaurate. Preferred surfactants for including in the emulsion are Tween 80 (polyoxyethylene sorbitan monooleate), Span 85 (sorbitan trioleate), lecithin and Triton X-100. As mentioned above, detergents such as Tween 80 may contribute to the thermal stability seen in the examples below.

Mixtures of surfactants can be used *e.g.* Tween 80/Span 85 mixtures. A combination of a polyoxyethylene sorbitan ester such as polyoxyethylene sorbitan monooleate (Tween 80) and an octoxynol such as t-octylphenoxypolyethoxyethanol (Triton X-100) is also suitable. Another useful combination comprises laureth 9 plus a polyoxyethylene sorbitan ester and/or an octoxynol.

Preferred amounts of surfactants (% by weight) are: polyoxyethylene sorbitan esters (such as Tween 80) 0.01 to 1%, in particular about 0.1 %; octyl- or nonylphenoxy polyoxyethanols (such as Triton X-100, or other detergents in the Triton series) 0.001 to 0.1 %, in particular 0.005 to 0.02%; polyoxyethylene ethers (such as laureth 9) 0.1 to 20 %, preferably 0.1 to 10 % and in particular 0.1 to 1 % or about 0.5%.

Specific oil-in-water emulsion adjuvants useful with the invention include, but are not limited to:

- A submicron emulsion of squalene, Tween 80, and Span 85. The composition of the emulsion by volume can be about 5% squalene, about 0.5% polysorbate 80 and about 0.5% Span 85. In weight terms, these ratios become 4.3% squalene, 0.5% polysorbate 80 and 0.48% Span 85. This adjuvant is known as 'MF59' [16-18], as described in more detail in Chapter 10 of ref. 19 and chapter 12 of ref. 20. The MF59 emulsion advantageously includes citrate ions *e.g.* 10mM sodium citrate buffer.
- An emulsion comprising squalene, an α-tocopherol, and polysorbate 80. These emulsions may have from 2 to 10% squalene, from 2 to 10% tocopherol and from 0.3 to 3% Tween 80, and the weight ratio of squalene:tocopherol is preferably ≤ 1 (*e.g.* 0.90) as this provides a more stable emulsion. Squalene and Tween 80 may be present volume ratio of about 5:2, or at a weight ratio of about 11:5. One such emulsion can be made by dissolving Tween 80 in PBS to give a 2% solution, then mixing 90ml of this solution with a mixture of (5g of DL-α-tocopherol and 5ml squalene), then microfluidising the mixture. The resulting emulsion may have submicron oil droplets *e.g.* with an average diameter of between 100 and 250nm, preferably about 180nm.
- An emulsion of squalene, a tocopherol, and a Triton detergent (*e.g.* Triton X-100). The emulsion may also include a 3d-MPL (see below). The emulsion may contain a phosphate buffer.
- An emulsion comprising a polysorbate (*e.g.* polysorbate 80), a Triton detergent (*e.g.* Triton X-100) and a tocopherol (*e.g.* an α-tocopherol succinate). The emulsion may include these three components at a mass ratio of about 75:11:10 (*e.g.* 750μg/ml polysorbate 80, 110μg/ml Triton X-100 and 100μg/ml α-tocopherol succinate), and these concentrations should include any contribution of these components from antigens. The emulsion may also include squalene. The emulsion may also include a 3d-MPL (see below). The aqueous phase may contain a phosphate buffer.
- An emulsion of squalane, polysorbate 80 and poloxamer 401 ("Pluronic™ L121"). The emulsion can be formulated in phosphate buffered saline, pH 7.4. This emulsion is a useful

delivery vehicle for muramyl dipeptides, and has been used with threonyl-MDP in the "SAF-1" adjuvant [21] (0.05-1% Thr-MDP, 5% squalane, 2.5% Pluronic L121 and 0.2% polysorbate 80). It can also be used without the Thr-MDP, as in the "AF" adjuvant [22] (5% squalane, 1.25% Pluronic L121 and 0.2% polysorbate 80). Microfluidisation is preferred.

- An emulsion comprising squalene, an aqueous solvent, a polyoxyethylene alkyl ether hydrophilic nonionic surfactant (*e.g.* polyoxyethylene (12) cetostearyl ether) and a hydrophobic nonionic surfactant (*e.g.* a sorbitan ester or mannide ester, such as sorbitan monoleate or 'Span 80'). The emulsion is preferably thermoreversible and/or has at least 90% of the oil droplets (by volume) with a size less than 200 nm [23]. The emulsion may also include one or more of: alditol; a cryoprotective agent (*e.g.* a sugar, such as dodecylmaltoside and/or sucrose); and/or an alkylpolyglycoside. Such emulsions may be lyophilized.
- An emulsion having from 0.5-50% of an oil, 0.1-10% of a phospholipid, and 0.05-5% of a non-ionic surfactant. As described in reference 24, preferred phospholipid components are phosphatidylcholine, phosphatidylethanolamine, phosphatidylserine, phosphatidylinositol, phosphatidylglycerol, phosphatidic acid, sphingomyelin and cardiolipin. Submicron droplet sizes are advantageous.
- A submicron oil-in-water emulsion of a non-metabolisable oil (such as light mineral oil) and at least one surfactant (such as lecithin, Tween 80 or Span 80). Additives may be included, such as QuilA saponin, cholesterol, a saponin-lipophile conjugate (such as GPI-0100, described in reference 25, produced by addition of aliphatic amine to desacylsaponin via the carboxyl group of glucuronic acid), dimethyidioctadecylammonium bromide and/or N,N-dioctadecyl-N,N-bis (2-hydroxyethyl)propanediamine.
- An emulsion comprising a mineral oil, a non-ionic lipophilic ethoxylated fatty alcohol, and a non-ionic hydrophilic surfactant (*e.g.* an ethoxylated fatty alcohol and/or polyoxyethylene-polyoxypropylene block copolymer) [26].
- An emulsion comprising a mineral oil, a non-ionic hydrophilic ethoxylated fatty alcohol, and a non-ionic lipophilic surfactant (*e.g.* an ethoxylated fatty alcohol and/or polyoxyethylene-polyoxypropylene block copolymer) [26].
- An emulsion in which a saponin (*e.g.* QuilA or QS21) and a sterol (*e.g.* a cholesterol) are associated as helical micelles [27].

Antigens and adjuvants in a composition will typically be in admixture at the time of delivery to a patient. The emulsions may be mixed with antigen during manufacture, or extemporaneously, at the time of delivery. Thus the adjuvant and antigen may be kept separately in a packaged or distributed vaccine, ready for final formulation at the time of use. The antigen will generally be in an aqueous form, such that the vaccine is finally prepared by mixing two liquids. The volume ratio of the two liquids for mixing can vary (*e.g.* between 5:1 and 1:5) but is generally about 1:1.

C. Saponin formulations [chapter 22 of ref. 19]

Saponin formulations may also be used as adjuvants in the invention. Saponins are a heterogeneous group of sterol glycosides and triterpenoid glycosides that are found in the bark, leaves, stems, roots and even flowers of a wide range of plant species. Saponin from the bark of the *Quillaia saponaria* Molina tree have been widely studied as adjuvants. Saponin can also be commercially obtained from *Smilax ornata* (sarsaprilla), *Gypsophilla paniculata* (brides veil), and *Saponaria officianalis* (soap root). Saponin adjuvant formulations include purified formulations, such as QS21, as well as lipid formulations, such as ISCOMs. QS21 is marketed as Stimulon™.

Saponin compositions have been purified using HPLC and RP-HPLC. Specific purified fractions using these techniques have been identified, including QS7, QS17, QS18, QS21, QH-A, QH-B and QH-C. Preferably, the saponin is QS21. A method of production of QS21 is disclosed in ref. 28. Saponin formulations may also comprise a sterol, such as cholesterol [29].

Combinations of saponins and cholesterols can be used to form unique particles called immunostimulating complexs (ISCOMs; see chapter 23 of ref. 19; also refs 30 & 31). ISCOMs typically also include a phospholipid such as phosphatidylethanolamine or phosphatidylcholine. Any known saponin can be used in ISCOMs. Preferably, the ISCOM includes one or more of QuilA, QHA & QHC. Optionally, the ISCOMS may be devoid of additional detergent [32].

A review of the development of saponin based adjuvants can be found in refs. 33 & 34.

D. Bacterial or microbial derivatives

Adjuvants suitable for use in the invention include bacterial or microbial derivatives such as non-toxic derivatives of enterobacterial lipopolysaccharide (LPS), Lipid A derivatives, immunostimulatory oligonucleotides and ADP-ribosylating toxins and detoxified derivatives thereof.

Non-toxic derivatives of LPS include monophosphoryl lipid A (MPL) and 3-O-deacylated MPL (3dMPL). 3dMPL is a mixture of 3 de-O-acylated monophosphoryl lipid A with 4, 5 or 6 acylated chains. A preferred "small particle" form of 3 De-O-acylated monophosphoryl lipid A is disclosed in ref. 35. Such "small particles" of 3dMPL are small enough to be sterile filtered through a 0.22μm membrane [35]. Other non-toxic LPS derivatives include monophosphoryl lipid A mimics, such as aminoalkyl glucosaminide phosphate derivatives *e.g.* RC-529 [36,37].

Lipid A derivatives include derivatives of lipid A from *Escherichia coli* such as OM-174. OM-174 is described for example in refs. 38 & 39.

Immunostimulatory oligonucleotides suitable for use as adjuvants in the invention include nucleotide sequences containing a CpG motif (a dinucleotide sequence containing an unmethylated cytosine linked by a phosphate bond to a guanosine). Double-stranded RNAs and oligonucleotides containing palindromic or poly(dG) sequences have also been shown to be immunostimulatory.

The CpG's can include nucleotide modifications/analogs such as phosphorothioate modifications and can be double-stranded or single-stranded. References 40, 41 and 42 disclose possible analog substitutions *e.g.* replacement of guanosine with 2'-deoxy-7-deazaguanosine. The adjuvant effect of CpG oligonucleotides is further discussed in refs. 43-48.

The CpG sequence may be directed to TLR9, such as the motif GTCGTT or TTCGTT [49]. The CpG sequence may be specific for inducing a Th1 immune response, such as a CpG-A ODN, or it may be more specific for inducing a B cell response, such a CpG-B ODN. CpG-A and CpG-B ODNs are discussed in refs. 50-52. Preferably, the CpG is a CpG-A ODN.

Preferably, the CpG oligonucleotide is constructed so that the 5' end is accessible for receptor recognition. Optionally, two CpG oligonucleotide sequences may be attached at their 3' ends to form "immunomers". See, for example, refs. 53-55.

A particularly useful adjuvant based around immunostimulatory oligonucleotides is known as IC-31™ [56-58]. Thus an adjuvant used with the invention may comprise a mixture of (i) an oligonucleotide (*e.g.* between 15-40 nucleotides) including at least one (and preferably multiple) CpI motifs (*i.e.* a cytosine linked to an inosine to form a dinucleotide), and (ii) a polycationic polymer, such as an oligopeptide (*e.g.* between 5-20 amino acids) including at least one (and preferably multiple) Lys-Arg-Lys tripeptide sequence(s). The oligonucleotide may be a deoxynucleotide comprising 26-mer sequence 5'-$(IC)_{13}$-3' (SEQ ID NO: 7). The polycationic polymer may be a peptide comprising 11-mer amino acid sequence KLKLLLLLKLK (SEQ ID NO: 6). This combination of SEQ ID NOs: 6 and 7 provides the IC-31™ adjuvant.

Bacterial ADP-ribosylating toxins and detoxified derivatives thereof may be used as adjuvants in the invention. Preferably, the protein is derived from *E.coli* (*E.coli* heat labile enterotoxin "LT"), cholera ("CT"), or pertussis ("PT"). The use of detoxified ADP-ribosylating toxins as mucosal adjuvants is described in ref. 59 and as parenteral adjuvants in ref. 60. The toxin or toxoid is preferably in the form of a holotoxin, comprising both A and B subunits. Preferably, the A subunit contains a detoxifying mutation; preferably the B subunit is not mutated. Preferably, the adjuvant is a detoxified LT mutant such as LT-K63, LT-R72, and LT-G192. The use of ADP-ribosylating toxins and detoxified derivatives thereof, particularly LT-K63 and LT-R72, as adjuvants can be found in refs. 61-68. A useful CT mutant is or CT-E29H [69]. Numerical reference for amino acid substitutions is preferably based on the alignments of the A and B subunits of ADP-ribosylating toxins set forth in ref. 70, specifically incorporated herein by reference in its entirety.

E. Human immunomodulators

Human immunomodulators suitable for use as adjuvants in the invention include cytokines, such as interleukins (*e.g.* IL-1, IL-2, IL-4, IL-5, IL-6, IL-7, IL-12 [71], *etc.*) [72], interferons (*e.g.* interferon-γ), macrophage colony stimulating factor, and tumor necrosis factor. A preferred immunomodulator is IL-12.

F. Bioadhesives and Mucoadhesives

Bioadhesives and mucoadhesives may also be used as adjuvants in the invention. Suitable bioadhesives include esterified hyaluronic acid microspheres [73] or mucoadhesives such as cross-linked derivatives of poly(acrylic acid), polyvinyl alcohol, polyvinyl pyrollidone, polysaccharides and carboxymethylcellulose. Chitosan and derivatives thereof may also be used as adjuvants in the invention [74].

G. Microparticles

Microparticles may also be used as adjuvants in the invention. Microparticles (*i.e.* a particle of ~100nm to ~150μm in diameter, more preferably ~200nm to ~30μm in diameter, and most preferably ~500nm to ~10μm in diameter) formed from materials that are biodegradable and non-toxic (*e.g.* a poly(α-hydroxy acid), a polyhydroxybutyric acid, a polyorthoester, a polyanhydride, a polycaprolactone, *etc.*), with poly(lactide-co-glycolide) are preferred, optionally treated to have a negatively-charged surface (*e.g.* with SDS) or a positively-charged surface (*e.g.* with a cationic detergent, such as CTAB).

H. Liposomes (Chapters 13 & 14 of ref. 19)

Examples of liposome formulations suitable for use as adjuvants are described in refs. 75-77.

I. Imidazoquinolone Compounds.

Examples of imidazoquinolone compounds suitable for use adjuvants in the invention include Imiquamod and its homologues (*e.g.* "Resiquimod 3M"), described further in refs. 78 and 79.

The invention may also comprise combinations of aspects of one or more of the adjuvants identified above. For example, the following adjuvant compositions may be used in the invention: (1) a saponin and an oil-in-water emulsion [80]; (2) a saponin (*e.g.* QS21) + a non-toxic LPS derivative (*e.g.* 3dMPL) [81]; (3) a saponin (*e.g.* QS21) + a non-toxic LPS derivative (*e.g.* 3dMPL) + a cholesterol; (4) a saponin (*e.g.* QS21) + 3dMPL + IL-12 (optionally + a sterol) [82]; (5) combinations of 3dMPL with, for example, QS21 and/or oil-in-water emulsions [83]; (6) SAF, containing 10% squalane, 0.4% Tween 80™, 5% pluronic-block polymer L121, and thr-MDP, either microfluidized into a submicron emulsion or vortexed to generate a larger particle size emulsion. (7) Ribi™ adjuvant system (RAS), (Ribi Immunochem) containing 2% squalene, 0.2% Tween 80, and one or more bacterial cell wall components from the group consisting of monophosphorylipid A (MPL), trehalose dimycolate (TDM), and cell wall skeleton (CWS), preferably MPL + CWS (Detox™); and (8) one or more mineral salts (such as an aluminum salt) + a non-toxic derivative of LPS (such as 3dMPL).

Other substances that act as immunostimulating agents are disclosed in chapter 7 of ref. 19.

An aluminium hydroxide adjuvant is useful, and antigens are generally adsorbed to this salt. Oil-in-water emulsions comprising squalene, with submicron oil droplets, are also preferred, particularly in the elderly. Useful adjuvant combinations include combinations of Th1 and Th2 adjuvants such as

CpG & an aluminium salt, or resiquimod & an aluminium salt. A combination of an aluminium salt and 3dMPL may be used.

Immunisation

In addition to providing immunogenic compositions as described above, the invention also provides a method for raising an antibody response in a mammal, comprising administering an immunogenic composition of the invention to the mammal. The antibody response is preferably a protective antibody response. The invention also provides compositions of the invention for use in such methods.

The invention also provides a method for protecting a mammal against a *Shigella* infection and/or disease (*e.g.* against shigellosis, Reiter's syndrome, and/or hemolytic uremic syndrome), comprising administering to the mammal an immunogenic composition of the invention.

The invention provides compositions of the invention for use as medicaments (*e.g.* as immunogenic compositions or as vaccines). It also provides the use of vesicles of the invention in the manufacture of a medicament for preventing a *Shigella* infection in a mammal *e.g.* for preventing shigellosis, Reiter's syndrome, and/or hemolytic uremic syndrome. It also provides the use of a bleb protein (as defined above) in the manufacture of a bleb-free medicament for preventing a *Shigella* infection in a mammal *e.g.* for preventing shigellosis.

The mammal is preferably a human. The human may be an adult or, preferably, a child. Where the vaccine is for prophylactic use, the human is preferably a child (*e.g.* a toddler or infant); where the vaccine is for therapeutic use, the human is preferably an adult. A vaccine intended for children may also be administered to adults *e.g.* to assess safety, dosage, immunogenicity, *etc.*

The uses and methods are particularly useful for preventing/treating diseases including, but not limited to, shigellosis, Reiter's syndrome, and/or hemolytic uremic syndrome

Efficacy of therapeutic treatment can be tested by monitoring *Shigella* infection after administration of the composition of the invention. Efficacy of prophylactic treatment can be tested by monitoring immune responses against immunogenic proteins in the blebs or other antigens after administration of the composition. Immunogenicity of compositions of the invention can be determined by administering them to test subjects (*e.g.* children 12-16 months age) and then determining standard serological parameters. These immune responses will generally be determined around 4 weeks after administration of the composition, and compared to values determined before administration of the composition. Where more than one dose of the composition is administered, more than one post-administration determination may be made.

Compositions of the invention will generally be administered directly to a patient. Direct delivery may be accomplished by parenteral injection (*e.g.* subcutaneously, intraperitoneally, intravenously, intramuscularly, or to the interstitial space of a tissue), or by rectal, oral, vaginal, topical,

transdermal, intranasal, ocular, aural, pulmonary or other mucosal administration. Intramuscular administration to the thigh or the upper arm is preferred. Injection may be via a needle (*e.g.* a hypodermic needle), but needle-free injection may alternatively be used. A typical intramuscular dose is about 0.5 ml.

The invention may be used to elicit systemic and/or mucosal immunity.

Dosage treatment can be a single dose schedule or a multiple dose schedule. Multiple doses may be used in a primary immunisation schedule and/or in a booster immunisation schedule. A primary dose schedule may be followed by a booster dose schedule. Suitable timing between priming doses (*e.g.* between 4-16 weeks), and between priming and boosting, can be routinely determined.

General

The term "comprising" encompasses "including" as well as "consisting" *e.g.* a composition "comprising" X may consist exclusively of X or may include something additional *e.g.* X + Y.

The term "about" in relation to a numerical value *x* is optional and means, for example, $x \pm 10\%$.

The word "substantially" does not exclude "completely" *e.g.* a composition which is "substantially free" from Y may be completely free from Y. Where necessary, the word "substantially" may be omitted from the definition of the invention.

References to a percentage sequence identity between two amino acid sequences means that, when aligned, that percentage of amino acids are the same in comparing the two sequences. This alignment and the percent homology or sequence identity can be determined using software programs known in the art, for example those described in section 7.7.18 of reference 84. A preferred alignment is determined by the Smith-Waterman homology search algorithm using an affine gap search with a gap open penalty of 12 and a gap extension penalty of 2, BLOSUM matrix of 62. The Smith-Waterman homology search algorithm is well known and is disclosed in reference 85.

"GI" numbering is used above. A GI number, or "GenInfo Identifier", is a series of digits assigned consecutively to each sequence record processed by NCBI when sequences are added to its databases. The GI number bears no resemblance to the accession number of the sequence record. When a sequence is updated (*e.g.* for correction, or to add more annotation or information) then it receives a new GI number. Thus the sequence associated with a given GI number is never changed.

Where the invention concerns an "epitope", this epitope may be a B-cell epitope and/or a T-cell epitope. Such epitopes can be identified empirically (*e.g.* using PEPSCAN [86,87] or similar methods), or they can be predicted (*e.g.* using the Jameson-Wolf antigenic index [88], matrix-based approaches [89], MAPITOPE [90], TEPITOPE [91,92], neural networks [93], OptiMer & EpiMer [94, 95], ADEPT [96], Tsites [97], hydrophilicity [98], antigenic index [99] or the methods disclosed in references 100-101, *etc.*). Epitopes are the parts of an antigen that are recognised by and bind to

the antigen binding sites of antibodies or T-cell receptors, and they may also be referred to as "antigenic determinants".

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 shows an electron micrograph of blebs of the invention purified from culture.

Figure 2 shows 2D SDS-PAGE of blebs from *S. sonnei ΔtolR ΔgalU.*

Figure 3 shows LPS of blebs in various indicated strains, stained with anti-core antibody.

Figure 4 shows an immunoblot of 2D-separated proteins of blebs using serum from immunised mice.

Figure 5 shows SDS-PAGE of bacteria grown in different conditions.

Figure 6 shows adsorbed proteins in blebs. Lanes from left to right: 1) protein molecular weight marker, 2) Ss OMB 10 μg, 3) Ss OMB 2 μg, 4) Ss OMB 10 μg adsorbed on alum for 1 month.

Figure 7 shows FACS data for indicated strains.

MODES FOR CARRYING OUT THE INVENTION

Preparation of mutant of S.sonnei

The *tolR* gene of wild-type *S.sonnei* 53G was deleted using the λ Red system [11,102]. Competent cells transformed with the λ Red plasmids are prepared and then transformed with a linear fragment designed to swap the *tolR* gene for an antibiotic resistance gene by homologous recombination. Clones that have integrated the fragment into the chromosome are selected by resistance to the antibiotic and deletion of the *tolR* is verified by PCR or other techniques. The temperature sensitive λ Red plasmids can then be removed by growth of the new clones at 37°C.

The lack of TolR expression in this *ΔtolR* mutant was confirmed and, compared to the original wild-type isolate, it was confirmed to release more blebs into culture medium during growth.

The *galU* gene was also deleted in a similar way, to provide a *ΔgalU* single mutant and a *ΔtolRΔgalU* double mutant. Blebs released by mutants are confirmed to have a defective LPS lacking O antigen.

A *ΔtolRΔmsbB* double mutant strain with modified LPS is prepared in the same way.

The virulence plasmid has also been removed from the *ΔtolR* and *ΔtolRΔmsbB* strains.

Preparation of mutant of S.flexneri

The *tolR* gene of *S. flexneri* was deleted using the λ Red system as described above for *S. sonnei.* O antigen biosynthesis in *S. flexneri* was abolished by deletion of a chromosomal fragment comprising the complete *rfbG* gene and as well as parts of *rfbF* and *rfc,* resulting in activation of all three genes. The deletion was generated using the λ Red system and is abbreviated as Δ*rfbG.*

A Δ*tolR*Δ*rfbG* double mutant has been generated in the same way.

A Δ*tolR*Δ*htrB* double mutant containing modified LPS has been generated in the same way.

The virulence plasmid has also been removed from these strains.

Purification of blebs

Fermentation of the double mutant *ΔtolRΔgalU* strain was run under the following conditions: pH 7.1, 37°C, dissolved oxygen maintained at 30% saturation by controlling agitation and setting maximum aeration. The pH was controlled by addition of 4M ammonium hydroxide. The foam was controlled by addition of 10% PPG during the run. The medium consisted of the following components: KH_2PO_4 5g/l, K_2HPO_4 20g/l and yeast extract 30g/l. After the medium was sterilized by autoclaving, glycerol 15g/l and $MgSO_4$ 2mM were added prior to inoculation. The culture inoculum was 5% of the fermentor volume. The fermentation process took approximately 13 hours and cell concentration was measured as optical density at 600nm.

The fermentation process of the *S.sonnei ΔtolRΔmsbB* double mutant strain was performed with defined medium: glycerol 30 g/l, KH_2PO_4 13.3 g/l, $(NH_4)_2HPO_4$ 4 g/l, $MgSO_4 \cdot 7H_2O$ (1M) 2ml, citric acid 1.7 g/l, $CoCl_2 \cdot 6H_2O$ 2.5 mg/l, $MnCl_2 \cdot 4H_2O$ 15 mg/l, $CuCl_2 \cdot 2H_2O$ 1.5 mg/l, H_3BO_3 3 mg/l, $Na_2MoO_4 \cdot 2H_2O$ 2.5 mg/l, $Zn(CH_3COO)_2 \cdot 2H_2O$ 13 mg/l, ferric citrate 2μM, thiamine 50 mg/l, nicotinic acid 10 mg/l, L-acid aspartic 2.5g/l.

Vesicles produced in the fermentation broth were purified using two consecutive TFF (tangential flow filtration) steps: micro-filtration at 0.22μm and then a second micro-filtration at 0.1μm. During the first filtration step the vesicles were separated from biomass by TFF through a 0.22 μm pore size cassette. The biomass was first concentrated 4-fold and, after five diafiltration steps against PBS, the vesicles were collected in the filtrate. In the second filtration step the filtrate from the 0.22 μm TFF was further micro-filtered trough a 0.1 μm cut-off cassette, in order to purify the vesicles from soluble proteins. The vesicles could not pass through the filter cassette. After five diafiltration steps, the retentate containing the vesicles was collected.

The final purified product was observed with TEM (Figure 1). The blebs have a homogenous size of about 50 nm in diameter.

Blebs from *S.flexneri* mutants were purified in the same way after growing the various strains in yeast extract medium as used for *S.sonnei ΔtolRΔgalU.*

Bleb characterisation

A proteomic approach confirmed that the blebs are essentially pure outer membranes. Unlike conventional outer membrane vesicles (OMV) derived by disruption of the outer membrane, the blebs conserve lipophilic proteins and are essentially free of cytoplasmic and inner membrane components.

Blebs from *S.sonnei* and *S.flexneri* strains were denatured with a detergent and proteins were identified with a LC-MS/MS approach. Alternatively, blebs were separated with SDS page or 2D gel electrophoresis (Figure 2). Visible bands and spots were excised from the gel and proteins identified

via protein mass fingerprint. The relative amount of different proteins was studied with densitometer analysis of SDS-PAGE bands or spots from the 2D gel.

Figure 3 shows a shift in LPS mobility in the Δ*galU* mutant strain compared to wildtype *Shigella* and *E. coli* (all strains are in a ΔtolR background).

A second proteomic approach, based on surface digestion, was used to characterize exposed portions of membrane proteins. A set of proteins was identified as reactive with sera from mice immunized with the blebs and many of these have been found to be conserved in a large panel of strains. Little is known about the structure of most integral outer membrane proteins. The surfome of blebs was investigated by treatment with a protease and recovery and identification via LC-MS/MS of released peptides. As blebs should represent the surface of the whole living bacterial cell, this map should be representative of exposed proteins on the surface of *S.sonnei.*

By these and other approaches the 129 proteins listed in Table 1 have been seen in the blebs.

Bleb immunogenicity

Mice immunised with the blebs from the *ΔtolRΔgalU* strain produce serum which reacts with a 2D gel of the blebs as shown in Figure 4. Thus the blebs are immunogenic.

Mice received 2μg or 10μg *S.sonnei ΔtolRΔgalU* blebs (measured as total protein), with or without adjuvant (aluminium hydroxide or Freund's complete). A classical ELISA method was performed to analyze IgG production in sera obtained from immunization studies. Sera from all groups of mice demonstrated a high level production of bleb-specific IgG. No significant differences in IgG production were detected when blebs were used alone or in combination with an adjuvant. Tthe group immunized with the lower dose of 2μg showed the same level of bleb -specific IgG as the group immunized with 10μg, showing that a low dose vaccine may be achievable *i.e.* more doses per dollar. Blebs from other *S.sonnei* as well as *S.flexneri* strains were similarly immunogenic.

Sera raised against the blebs were tested for reactivity with three different bacteria: *S.sonnei* G53, *S.flexneri* 2a 2457T or *S.flexneri* 5 M90T. The samples were than stained with a labeled secondary Ab and were analyzed by flow cytometry. As shown in Figure 7, the *S.sonnei* and *S.flexneri* strains cross-react with the sera.

Therefore the bleb approach has a strong potential to produce effective and low-cost vaccines and can be extended to different Shigella strains towards a broad spectrum vaccine.

Bleb adsorption

Blebs were combined with aluminium hydroxide (2mg/ml) for adsorption. The adsorbed material was stored at 4°C for 1 day, 1 week or 1 month. The blebs were toatlyl adsorbed after 1 day and there was no evidence of desorption even after 1 month (Figure 6).

Iron-limiting growth

Figure 5 shows proteins expressed by *Shigella* grown under various conditions. In lane 4 the bacteria were grown in the presence of 200μM $FeSO_4$ whereas in lane 5 the culture had 200μM dypiridyl. The inset shows that three proteins are up-regulated under the iron-limiting conditions. These three proteins were identified as the FepA outer membrane receptor (GI 74311118), the colicin I receptor (GI 74312677), and the putative ferric siderophore receptor (GI 74313972). These proteins are well-conserved among *Shigella* spp. and *enterobacteriaceae* and are potentially highly immunogenic. Thus growth of *Shigella* under iron-limiting conditions can lead to the release of blebs which are, compared to normal growth conditions, enriched for these proteins.

It will be understood that the invention has been described by way of example only and modifications may be made whilst remaining within the scope and spirit of the invention.

TABLE 1

SEQ ID NO:	GI	Gene name	Definition
8	56480244	tolC	outer membrane channel protein [Shigella flexneri 2a str. 301]
9	74312736	ompC	outer membrane porin protein C [Shigella sonnei Ss046]
10	74311514	ompA	outer membrane protein A [Shigella sonnei Ss046]
11	110807342	SFV_3519	hypothetical protein SFV_3519 [Shigella flexneri 5 str. 8401]
12	56479734	ompX	outer membrane protein X [Shigella flexneri 2a str. 301]
13	24113033	slyB	putative outer membrane protein [Shigella flexneri 2a str. 301]
14	24112608	lolB	outer membrane lipoprotein LolB [Shigella flexneri 2a str. 301]
15	24111612	yaeT	outer membrane protein assembly factor YaeT [Shigella flexneri 2a str. 301]
16	187733369		outer membrane protein C [Shigella boydii CDC 3083-94]
17	24113066	Lpp	murein lipoprotein [Shigella flexneri 2a str. 301]
18	56479690	pal	peptidoglycan-associated outer membrane lipoprotein [Shigella flexneri 2a str. 301]
19	24115506	ecnB	entericidin B membrane lipoprotein [Shigella flexneri 2a str. 301]
20	30063370	yedD	hypothetical protein S2067 [Shigella flexneri 2a str. 2457T]
21	30064374	ygiW	hypothetical protein S3269 [Shigella flexneri 2a str. 2457T]
22	30065519	yjeI	hypothetical protein S4565 [Shigella flexneri 2a str. 2457T]
23	24111837	ybaY	hypothetical protein SF0398 [Shigella flexneri 2a str. 301]
24	24113773	SF2485	hypothetical protein SF2485 [Shigella flexneri 2a str. 301]
25	74313380	SSON_2966	hypothetical protein SSON_2966 [Shigella sonnei Ss046]
26	30063856	nlpB	lipoprotein [Shigella flexneri 2a str. 2457T]
27	145294038	exc	entry exclusion protein 2 [Shigella sonnei Ss046]
28	82775909	rlpB	LPS-assembly lipoprotein RplB [Shigella dysenteriae Sd197]
29	74311310	ybhC	putative pectinesterase [Shigella sonnei Ss046]

30	24114611	fkpA	FKBP-type peptidyl-prolyl cis-trans isomerase [Shigella flexneri 2a str. 301]
31	74312826	hisJ	histidine-binding periplasmic protein of high-affinity histidine transport system [Shigella sonnei Ss046]
32	24111599	htrA	serine endoprotease [Shigella flexneri 2a str. 301]
33	30062097	tolB	translocation protein TolB [Shigella flexneri 2a str. 2457T]
34	24111968	modA	molybdate transporter periplasmic protein [Shigella flexneri 2a str. 301]
35	24114628	ppiA	peptidyl-prolyl cis-trans isomerase A (rotamase A) [Shigella flexneri 2a str. 301]
36	24111499	surA	peptidyl-prolyl cis-trans isomerase SurA [Shigella flexneri 2a str. 301]
37	30062764	oppA	periplasmic oligopeptide binding protein [Shigella flexneri 2a str. 2457T]
38	30065614	osmY	periplasmic protein [Shigella flexneri 2a str. 2457T]
39	74311404	artJ	arginine 3rd transport system periplasmic binding protein [Shigella sonnei Ss046]
40	74311061	ushA	bifunctional UDP-sugar hydrolase/5'-nucleotidase periplasmic precursor [Shigella sonnei Ss046]
41	74311733	fliY	cystine transporter subunit [Shigella sonnei Ss046]
42	110805056	mdoG	glucan biosynthesis protein G [Shigella flexneri 5 str. 8401]
43	74312961	cysP	thiosulfate transporter subunit [Shigella sonnei Ss046]
44	24114441	yraP	hypothetical protein SF3191 [Shigella flexneri 2a str. 301]
45	74312191	SSON_1681	putative receptor [Shigella sonnei Ss046]
46	74312061	ydgA	hypothetical protein SSON_1546 [Shigella sonnei Ss046]
47	24111764	proC	pyrroline-5-carboxylate reductase [Shigella flexneri 2a str. 301]
48	24112431	SF1022	hypothetical protein SF1022 [Shigella flexneri 2a str. 301]
49	110806822	yggE	hypothetical protein SFV_2968 [Shigella flexneri 5 str. 8401]
50	74312071	ydgH	hypothetical protein SSON_1556 [Shigella sonnei Ss046]
51	74313729	yrbC	hypothetical protein SSON_3340 [Shigella sonnei Ss046]
52	24115498	groEL	chaperonin GroEL [Shigella flexneri 2a str. 301]
53	56479605	lpdA	dihydrolipoamide dehydrogenase [Shigella flexneri 2a str. 301]
54	24112862	osmE	DNA-binding transcriptional activator OsmE [Shigella flexneri 2a str. 301]
55	30065622	deoD	purine nucleoside phosphorylase [Shigella flexneri 2a str. 2457T]
56	24111996	sucC	succinyl-CoA synthetase subunit beta [Shigella flexneri 2a str. 301]
57	24113762	Crr	glucose-specific PTS system component [Shigella flexneri 2a str. 301]
58	24111463	dnaK	molecular chaperone DnaK [Shigella flexneri 2a str. 301]
59	74311033		glycoprotein-polysaccharide metabolism
60	30064444	yqjD	hypothetical protein S3349
61	82777539	ycbO	alkanesulfonate transporter substrate-binding
62	74313684	yraM	putative glycosylase
63	24113841	SF2558	OM protein assembly complex subunit YfgL
64	24112186	ybiS	hypothetical protein SF0769
65	24111697	tauA	taurine transporter substrate binding subunit
66	24115105	yifL	putative outer membrane lipoprotein
67	24113718	vacJ	lipoprotein precursor
68	1679580	phoN	nonspecific phosphatase precursor [Shigella flexneri]
69	13449092	mxiD	Type III secretion protein

70	24112703	pspA	phage shock protein PspA [Shigella flexneri 2a str. 301]
71	24112822	yeaF	hypothetical protein SF1441 [Shigella flexneri 2a str. 301]
72	24113297	SF1963	cystine transporter subunit
73	24113931	SF2652	outer membrane protein assembly complex subunit YfiO [Shigella flexneri 2a str. 301]
74	24114232	sigA	serine protease [S. flexneri 2a str. 301]
75	24115037	ATP-synt_ab_C	F0F1 ATP synthase subunit alpha
76	24115158	glnA	glutamine synthetase [Shigella flexneri 2a str. 301]
77	30061681	aceF	dihydrolipoamide acetyltransferase
78	30062108	sucD	succinyl-CoA synthetase subunit alpha
79	30062110	sucB	dihydrolipoamide succinyltransferase
80	30062117	gltA	type II citrate synthase
81	30062179	dacA	D-alanyl-D-alanine carboxypeptidase fraction A
82	30062295	glnH	glutamine ABC transporter periplasmic protein
83	30062539	agp	Glucose-1-phosphate/inositol phosphatase
84	30062760	adhE	bifunctional acetaldehyde-CoA/alcohol dehydrogenase
85	30062895	mdoD	glucan biosynthesis protein D
86	30062959	gapA	glyceraldehyde-3-phosphate dehydrogenase
87	30063091	rspA	starvation sensing protein
88	30063194	S1842	bifunctional cysteine desulfurase/selenocysteine lyase
89	30063263	zwf	glucose-6-phosphate 1-dehydrogenase
90	30063276	aspS	aspartyl-tRNA synthetase
91	30063294	sitA	Iron transport protein
92	30063449	yeeX	hypothetical protein S2177
93	30063472	hisB	imidazole glycerol-phosphate dehydratase/histidinol phosphatase
94	30063593	mglB	Galactose-binding transport protein; receptor for galactose taxis
95	30064126	eno	phosphopyruvate hydratase
96	30064248	tktA	*transketolase*
97	30064278	ansB	L-asparaginase II
98	30064289	S3169	superfamily I DNA helicase
99	30064503	yhbM	lipoprotein NlpI
100	30064729	rpoC	DNA-directed RNA polymerase subunit beta'
101	30064730	rpoB	DNA-directed RNA polymerase subunit beta
102	30064872	udp	uridine phosphorylase
103	30064882	pldA	phospholipase A
104	30064963	atpD	F0F1 ATP synthase subunit beta
105	30065048	iutA	*putative ferric siderophore receptor*
106	30065119	lldD	L-lactate dehydrogenase
107	30065247	nikA	Periplasmic binding proteins for nickel
108	30065291	glpD	glycerol-3-phosphate dehydrogenase
109	30065404	rpoA	DNA-directed RNA polymerase subunit alpha
110	30065544	hfq	RNA-binding protein Hfq
111	56479788	yccZ	exopolysaccharide export protein [Shigella flexneri 2a str. 301]
112	56480532	lamB	maltoporin [Shigella flexneri 2a str. 301]
113	58045130	sepA	SepA [Shigella flexneri]

114	74310732	aceE	pyruvate dehydrogenase subunit E1 [Shigella sonnei Ss046]
115	74310771	fhuA	ferrichrome outer membrane transporter [Shigella sonnei Ss046]
116	74311118	fepA	outer membrane receptor FepA [Shigella sonnei Ss046]
117	74311859	prc	Carboxy-terminal protease [Shigella sonni Ss046]
118	74312394	yciD	outer membrane protein W [Shigella sonnei Ss046]
119	74312453	prsA	ribose-phosphate pyrophosphokinase [Shigella sonnei Ss046]
120	74312677	cirA	colicin I receptor [Shigella sonnei Ss046]
121	74312761	glpQ	glycerophosphodiester phosphodiesterase [Shigella sonnei Ss046]
122	74312989	talA	transaldolase A [Shigella sonnei Ss046]
123	74313764	degQ	serine endoprotease [Shigella sonnei Ss046]
124	74314527	malE	maltose ABC transporter periplasmic protein [Shigella sonnei Ss046]
125	82543910	SBO_1406	major capsid protein [Shigella boydii Sb227]
126	82544504	ycdO	hypothetical protein SBO_2040 [Shigella boydii Sb227]
127	82545484	dsbC	thiol:disulfide interchange protein DsbC [Shigella boydii Sb227]
128	82777619	ybjP	putative lipoprotein [Shigella dysenteriae Sd197]
129	110807066	yhbN	hypothetical protein SFV_3230 [Shigella flexneri 5 str. 8401]
130	161486535	yajG	hypothetical protein S0385
131	187427808	tolC	outer membrane protein TolC [Shigella boydii CDC 3083-94]
132	187731061	SbBS512_E 3369	peptidase, M48B family [Shigella boydii CDC 3083-94]
133	187731375	SbBS512_E 3904	outer membrane lipoprotein, Slp family [Shigella boydii CDC 3083-94]
134	187733898	osmY	osmotically inducible protein Y [Shigella boydii CDC 3083-94]
135	187734005	bglX	beta-glucosidase, periplasmic [Shigella boydii CDC 3083-94]
136	30065453	pepA	leucyl aminopeptidase

SEQ ID NOs: 70, 71, 73, 74, 76, 111, 112, 114-129 & 131-135 were identified from *S.sonnei ΔtolR* blebs. SEQ ID NOs: 8-15 & 17-58 were identified from *S.sonnei ΔtolRΔgalU* blebs. SEQ ID NOs: 83, 94, 97 & 107 were identified from *S.flexneri ΔtolR* blebs. SEQ ID NOs: 68, 69, 72, 75, 77-82, 84-93, 95, 96, 98-106, 108-10, 113, 130 & 136 were identified from *S.flexneri ΔtolRΔrfbG* blebs. SEQ ID NOs: 60-67 were identified from surface digestion of *S.sonnei*.

Subset 1: SEQ ID NOs: 68, 69, 72, 75, 77-110, 113, 130 & 136.

Subset 2: SEQ ID NOs: 8-15, 17-58, 60-67, 70, 71, 73, 74, 76, 111, 112, 114-129 & 131-135.

Subset 3: SEQ ID NOs: 1-60.

NB: SEQ ID NO: 18 is the same as SEQ ID NO: 5; SEQ ID NO: 33 is the same as SEQ ID NO: 2; SEQ ID NOs: 9 & 16 are related (~97% identity); SEQ ID NOs: 23 & 59 are related (~98% identity).

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SEQUENCE LISTING IN ELECTRONIC FORM

In accordance with Section 111(1) of the Patent Rules, this description contains a sequence listing in electronic form in ASCII text format (file: 21159-587 Seq 30-APR-12 v1.txt).

A copy of the sequence listing in electronic form is available from the Canadian Intellectual Property Office.

CLAIMS

1. A *Shigella* bacterium which does not express a TolR protein, wherein the bacterium releases greater quantities of outer membrane blebs compared to the same bacterium that expresses a TolR protein.

2. The bacterium of claim 1, wherein the bacterium expresses TolA, TolB, TolQ and Pal.

3. A bacterium of claim 2 which is a ΔtolR strain of *Shigella*.

4. The bacterium of any one of claims 1-3, wherein the bacterium does not express a native *Shigella* lipopolysaccharide.

5. The bacterium of claim 4, wherein the bacterium does not express a native *Shigella* O antigen.

6. The bacterium of any one of claims 1-5, wherein the bacterium expresses native lipid A but the native lipid A structure is disrupted.

7. The bacterium of any one of claims 1-6, which is a *ΔtolRΔmsbB* or a *ΔtolRΔhtrB* strain.

8. The bacterium of claim 3, wherein the strain is a *ΔtolRΔgalU* strain.

9. The bacterium of any one of claims 1-8, wherein a *stxA* and/or *stxB* gene is inactivated.

10. A process for preparing *Shigella* blebs, comprising a step of separating the blebs from a culture medium comprising the bacterium of any one of claims 1 to 9, which have been grown under conditions which permit the release of blebs into the medium by the bacteria.

11. The process of claim 10, wherein the bacteria have been grown under iron-limiting conditions.

12. A method of preparing a hyperblebbing *Shigella* bacterium, comprising a step of modifying gene(s) encoding one or more components of a starting bacterium's Tol-Pal system such that the modification causes the bacterium, when grown in culture medium, to release greater quantities of outer membrane blebs into the medium than the starting bacterium, and *wherein the bacterium does not express a TolR protein*.

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13. A bleb isolated or obtainable from the bacterium of any one of claims 1 to 9, or from a bacterium obtainable by the method of claim 12, or by the process of claim 10 or 11, wherein the bacterium is a *ΔtolRΔgalU* strain.

14. A composition comprising blebs that, during culture of the bacterium of any one of claims 1 to 9 or the bacterium obtainable by the method of claim 12, are released into a culture medium, wherein the bacterium is a *ΔtolRΔgalU* strain.

15. The composition of claim 14, which does not comprise any living and/or whole bacteria.

16. Culture media comprising the bacterium of claims 1 to 9, or the bacterium obtainable by the method of claim 12, which have been grown under conditions which permit the release of blebs into the medium by the bacterium.

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FIGURE 1

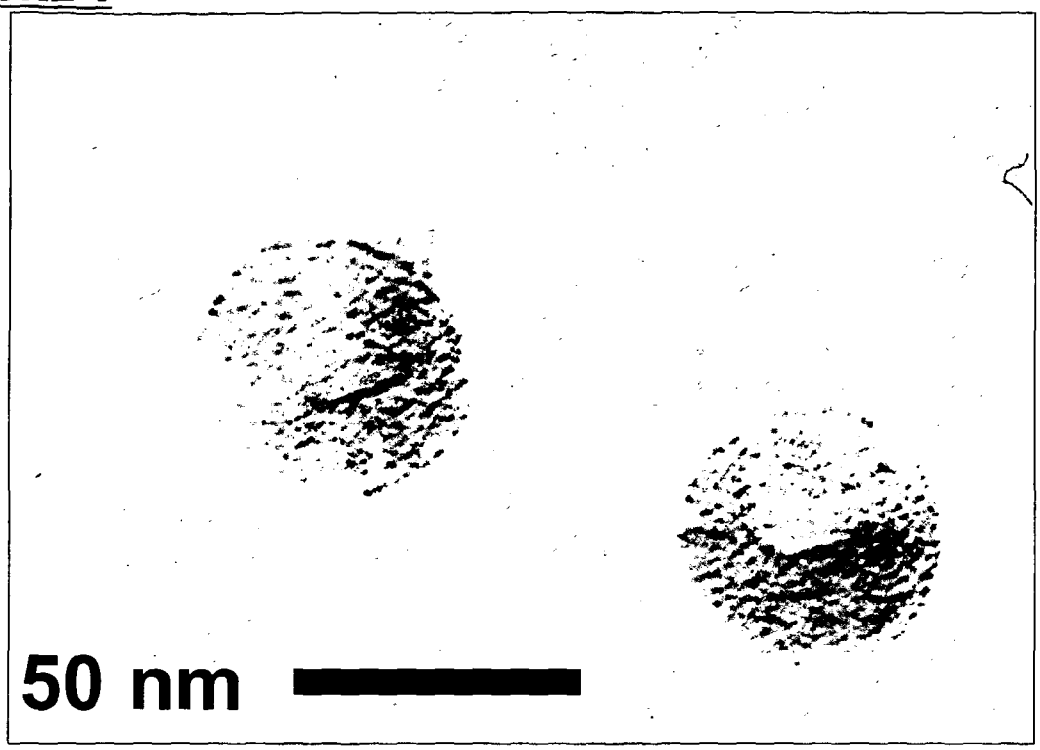


FIGURE 2

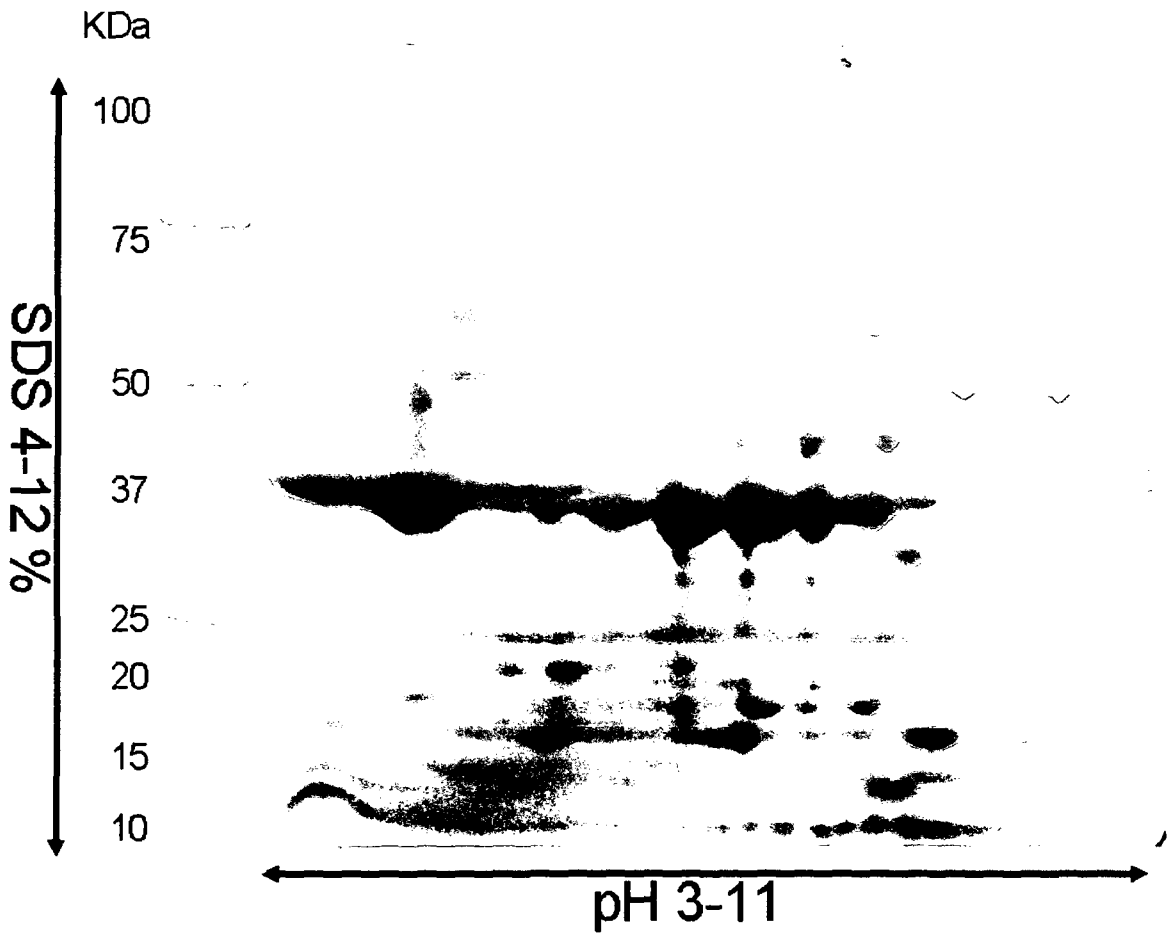


FIGURE 3

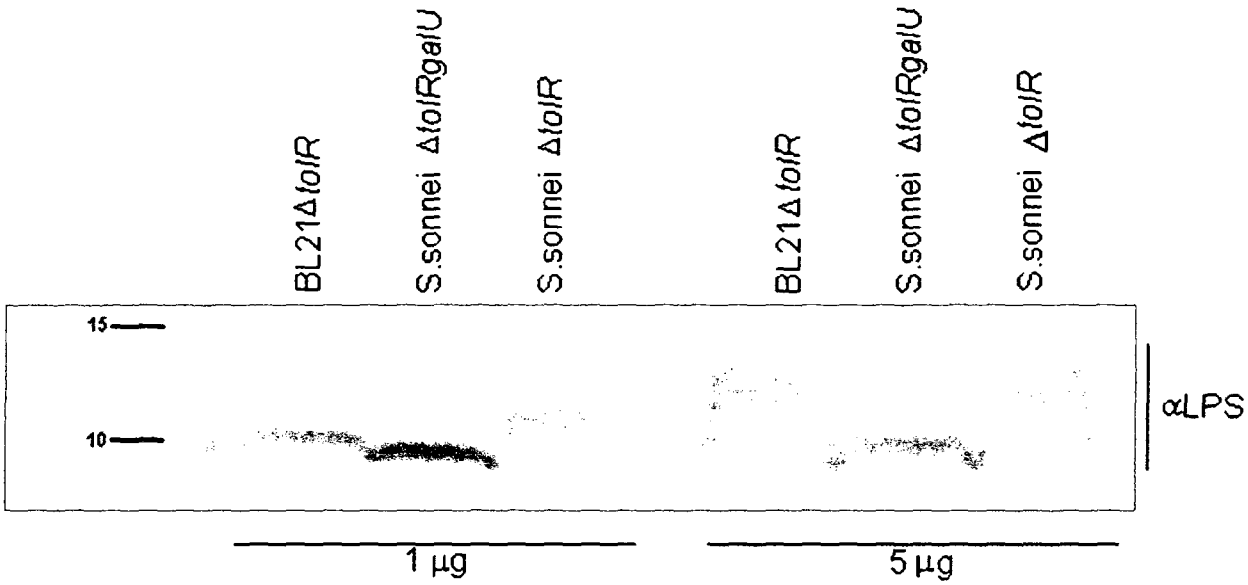


FIGURE 4

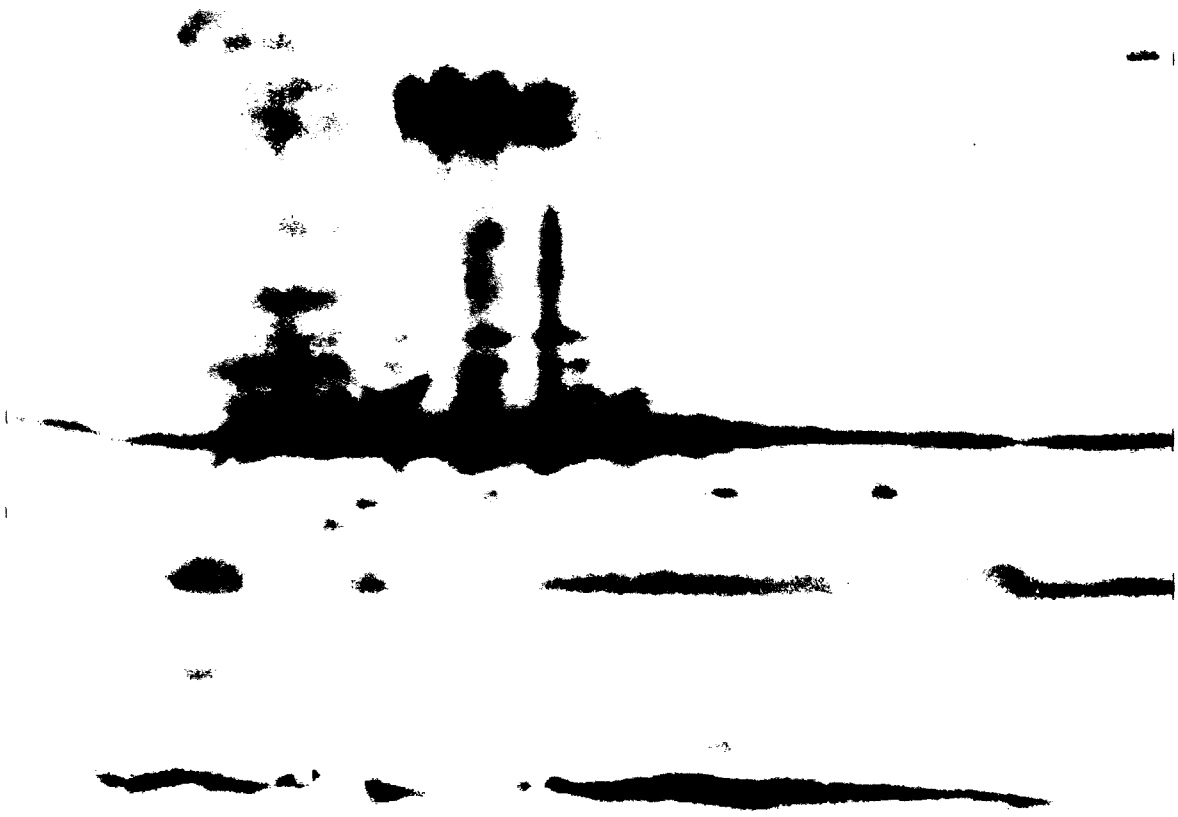


FIGURE 5

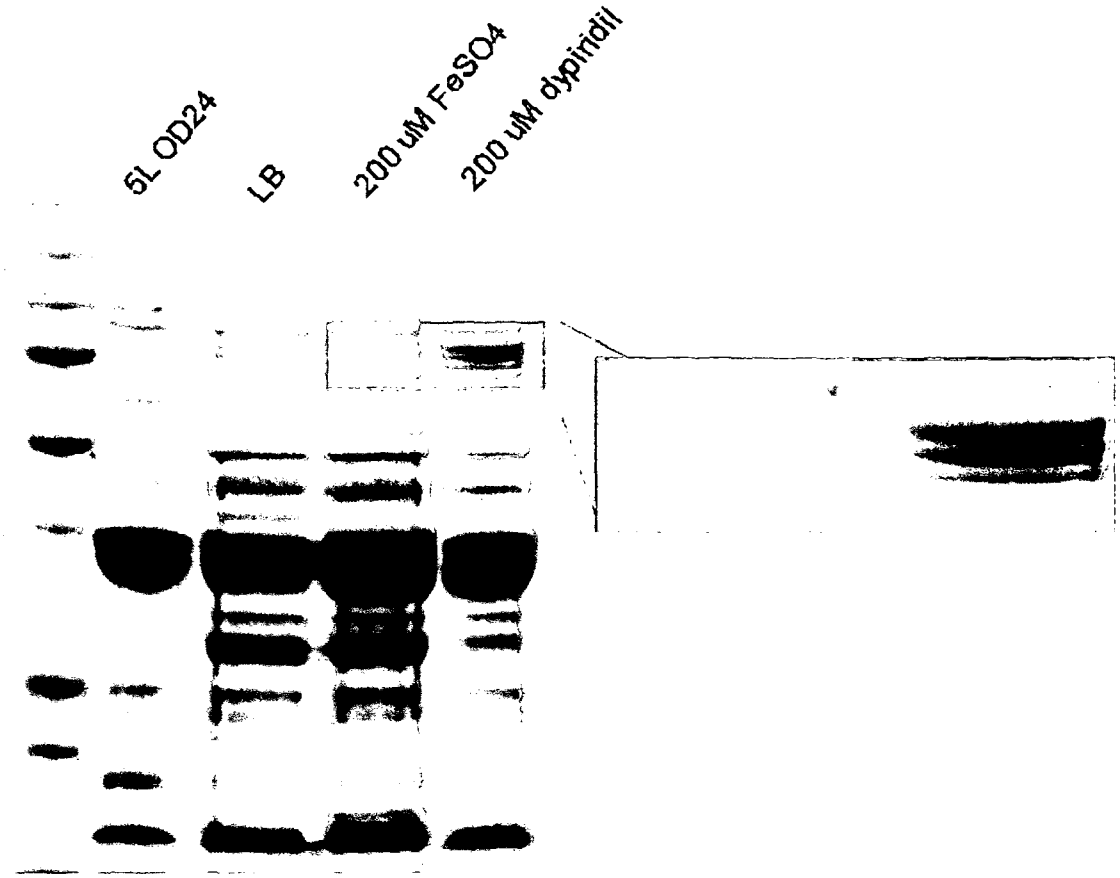


FIGURE 6

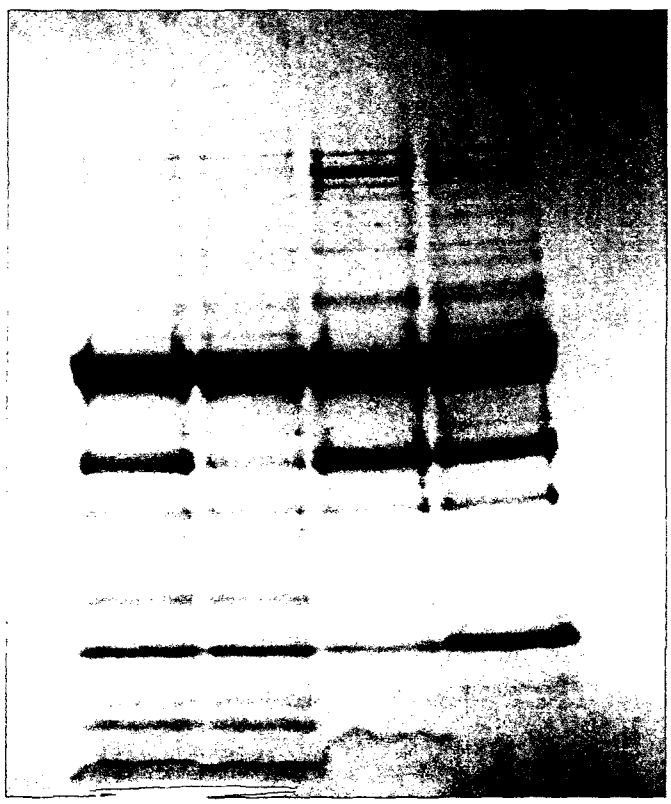
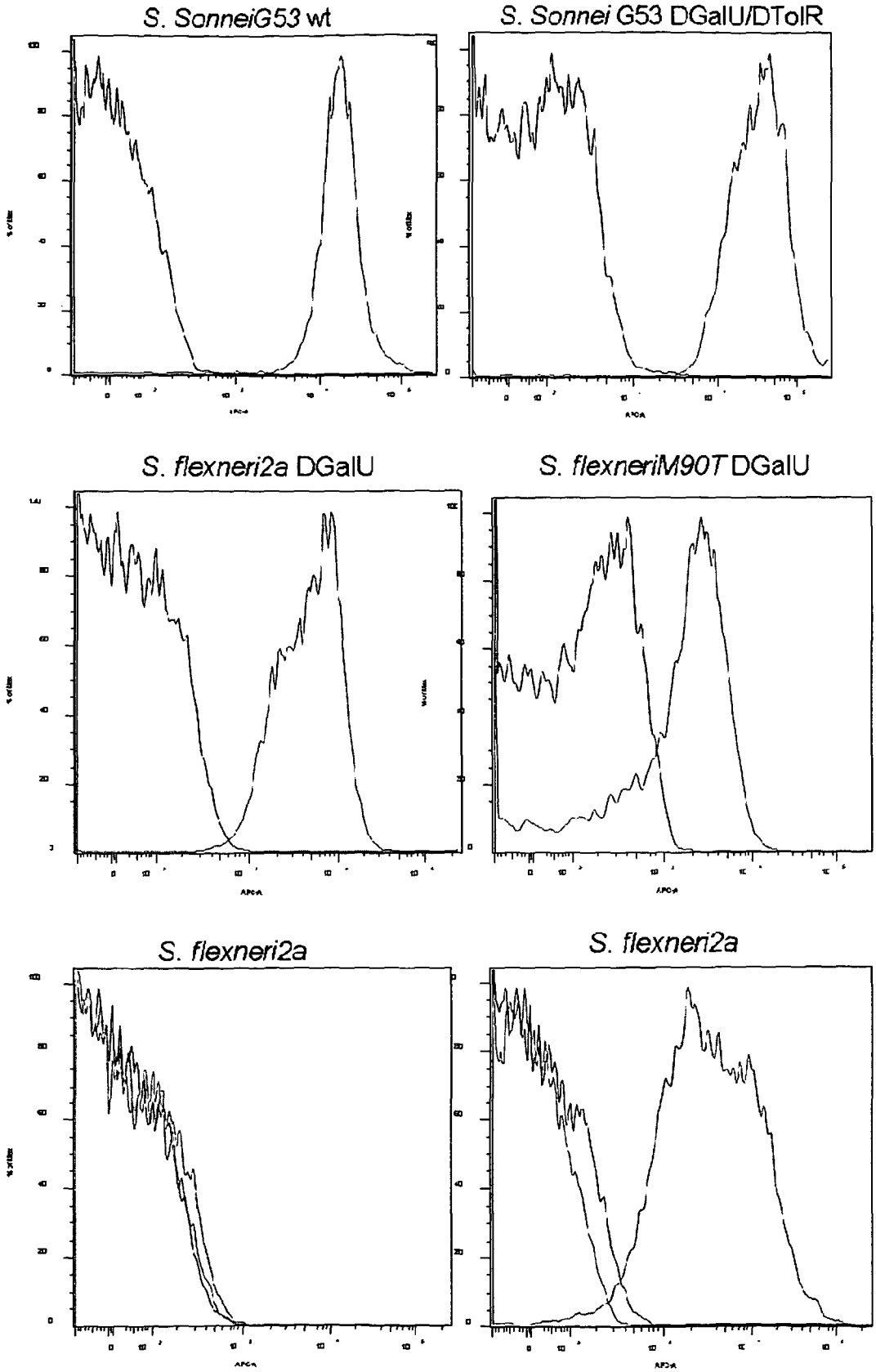
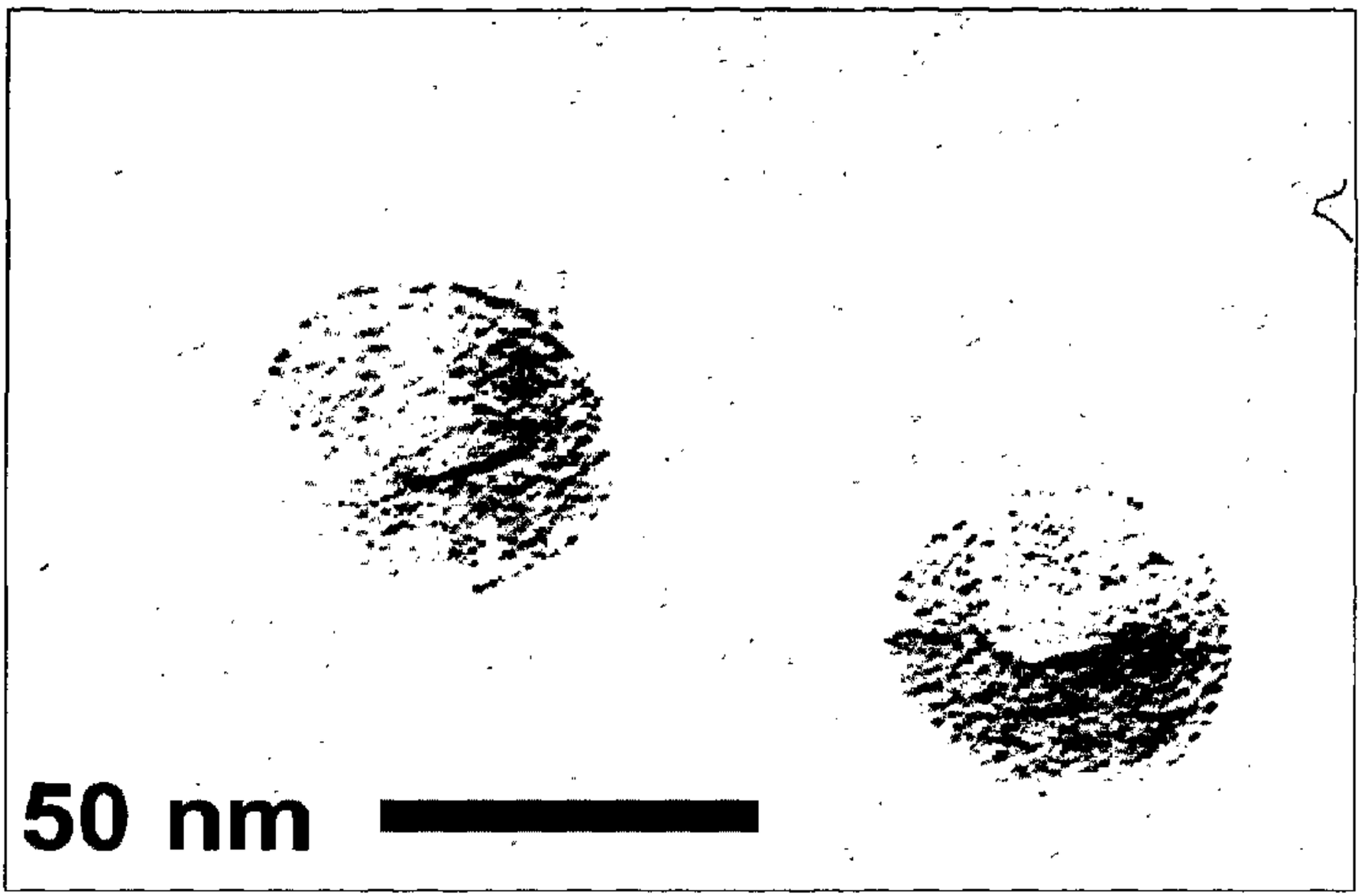


FIGURE 7


S. SonneiG53 wt
S. Sonnei G53 DGalU/DTolR
S. flexneri2a DGalU
S. flexneriM90T DGalU
S. flexneri2a
S. flexneri2a


50 nm