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HIGH AFFINITY HUMAN MONOCLONAL ANTIBODIES SPECIFIC FOR RSV F-PROTEIN

BACKGROUND OF THE INVENTION

Respiratory syncytial virus (RSV) is a Parmixovirus of the Pneumovirus genus which commonly infects the upper and lower respiratory tract. It is so contagious that by age two, a large percentage of children have been infected by it. Moreover, by age four, virtually all humans have an immunity to RSV.

Typically, RSV infections are mild, remaining localized in the upper respiratory tract and causing symptoms similar to a common cold which require no extensive treatment. However, in some subjects, e.g., immunosuppressed individuals such as infants, elderly persons or patients with underlying cardiopulmonary diseases, the virus may penetrate to the lower respiratory tract requiring hospitalization and breathing support. In some of these cases, RSV infection may cause permanent lung damage or even be life threatening. In the United States alone, RSV results in about 90,000 hospitalizations each year, and results in about 4500 deaths.

RSV appears in two major strain subgroups, A and B, primarily based on serological differences associated with the attachment glycoprotein, G. The major surface glycoprotein, i.e., the 90kD G protein, can differ up to 50% at the amino acid level between isolates Johnson et al, Proc. Natl. Acad. Sci. (1987), 84, 5625-5629. By contrast, a potential therapeutic target, the 70kD fusion (F) protein, is highly conserved across different RSV strains, about i.e., 89% on the amino acid level Johnson et al, J. Gen. Virol.(1988), 69, 2623-2628, Johnson et al, J. Virol. (1987), 10, 3163-3166, P.L. Collins, Plenum Press, NY (1991), 103-162. Moreover, it is known that antibodies elicited against F-protein of a given type are cross-reactive with the other type.

The F-protein is a heterodimer, generated from a linear precursor, consisting of disulfide-linked fragments of 48 and 23 kD respectively Walsh et al, *J. Gen. Virol*,

(1985), 66, 401-415. Inhibition of syncytia formation by polyclonal antibodies is associated with significant reaction to the 23kD fragment.

As noted, while RSV infections are usually mild, in some individuals RSV infections may be life threatening. Currently, severe RSV infection is treated by administration of the antiviral agent Ribavarin. However, while Ribavarin exhibits some efficacy in controlling RSV infection, its use is disfavored for several reasons. For example, it is highly expensive and may be administered only in hospitals. Other known RSV treatments only treat the symptoms of RSV infection and include the use of aerosolized bronchodilators in patients with bronchiolitis and corticosteroid therapy in patients with bronchiolitis and RSV pneumonia.

To date, RSV vaccines intended to boost antiviral protective antibodies have been largely unsuccessful. For example, a vaccine based on formalin-inactivated RSV that was tested approximately 25 years ago, induced antibodies that were deficient in fusion inhibiting activity Murphy et al. Clinical Microbiology (1988), 26, 1595-1597, and sometimes even exacerbated the disease. This may potentially be explained to the inability of the formalin inactivated virus to induce protective antibodies. While high antibody titers were measured in vaccine recipients, specific protective titers were lower than in the control population. This may be because formalin inactivated RSV does not display the necessary conformational epitopes required to elicit protective antibodies.

While there is no known effective RSV vaccine to date, there exists some clinical evidence that antibody therapy may confer protection against RSV infection in susceptible individuals, and may even clear an existing RSV infection. For example, it has been reported that newborn infants show a low incidence of severe bronchiolitis, which is hypothesized to be attributable to the presence of protective maternal antibodies Ogilvie et al. J. Med Virol (1981), 7, 263-271. Also, children who are immune to reinfection exhibit statistically higher anti-F-protein titers than those who are reinfected. Moreover, intravenous immune globulin (IVIG) prepared from high titer RSV-immune donors reduces nasal RSV shedding and improves oxygenation Hemming et al. Anti. Viral Agents and Chemotherapy (1987), 31, 1882-1886. Also, recent studies have suggested that the virus can be fought and lung

damage prevented by administering RSV-enriched immune globulin (RSVIG) Groothuis et al. The New England J. Med. (1993), 329, 1524-1530, K. McIntosh, The New England J. Med. (1993), 329, 1572-1573, J. R. Groothuis, Antiviral Research, (1994), 23, 1-10, Siber et al. J. Infectious Diseases (1994), 169, 1368-1373, Siber et al. J. Infectious Diseases (1992), 165:456-463.

Similarly, some animal studies suggest that antibody therapy with virus neutralizing antibodies may confer protection against RSV or even clear an existing RSV infection. For example, *in vitro* neutralizing mouse monoclonal antibodies have been reported to protect mice against infection and also to clear established RSV infections Taylor et al. J.Immunology, (1984), 52, 137-142, Stott et al., "Immune Responses, Virus Infections and Disease, I.R.L. Press, London (1989), 85-104. Also, monoclonal antibodies to the F-protein of RSV have shown high efficacy in both *in vitro* and *in vivo* RSV models Tempest et al. Bio/Technology, (1991), 9, 266-271, Crowe et al. Proc. Natl. Acad. Sci. (1994), 91, 1386-1390, Walsh et al. Infection and Immunity, (1984), 43, 756-758, Barbas III, et al. Proc. Natl. Acad. Sci. (1992), 89, 10164-10168, Walsh, et al. J. Gen. Virol. (1986), 67, 505-513. Antibody concentrations as low as 520-2000 μg/kg body weight have been reported to result in almost instant recovery in animal studies Crowe et al. Proc. Natl. Acad. Sci. (1994), 91, 1386-1390. Moreover, these monoclonal antibodies have been disclosed to neutralize both A and B strains, including laboratory strains and wildtype strains. These antibodies were administered either by injection Groothuis et al. The New England J. Med. (1993), 329, 1524-1530, Siber et al. J. Infectious Diseases (1994), 169, 1368-1373 or by aerosol Crowe et al. Proc. Natl. Acad. Sci. (1994), 91, 1386-1390.

Two different types of potentially therapeutic monoclonal antibodies to the RSV F-protein have been previously described in the literature, humanized murine antibodies Tempest et al, *Biol. Technology*, (1991) 9, 266-271, or true human antibodies (Fab fragments) Barbas III, et al. Proc. Natl. Acad. Sci. (1992), 89, 10164-10168. Humanized murine antibodies were generated by CDR grafting a cross-strain neutralizing murine anti-F-protein antibody onto a generic human Fc, as well as structural areas of the variable part. The human Fab fragments were

produced by combinatorial library technology using human bone marrow cells obtained from an HIV positive donor (immunocompromised). The therapeutic *in vivo* titers of the humanized and human RSV antibodies were 5 and 2 mg/kg body weight, respectively. It is noted, however, that the humanized antibodies were tested in a syncytia inhibition assay, whereas the human anti-RSV Fab fragments were assayed to determine their virus neutralization activity. Therefore, the results reported with the humanized and human anti-RSV antibodies are not directly comparable.

The Fab fragment generated by the combinatorial library technology were disclosed to be efficient in aerosol. This is probably because of the relatively small size of the molecule. These results are highly encouraging because a major target population for an RSV vaccine is infants. Therefore, aerosol is a particularly desirable mode of administration.

However, notwithstanding the previous published reports of humanized and Fab fragments specific to RSV, there still exists a significant need for improved anti-RSV antibodies having improved therapeutic potential, in particular anti-RSV antibodies which possess high affinity and specificity for the RSV F-protein which effectively neutralize and prevent RSV infection.

Antibody therapy can be subdivided into two principally different activities: (i) passive immunotherapy using intact non-labeled antibodies or labeled antibodies and (ii) active immunotherapy using anti-idiotypes for re-establishment of network balance in autoimmunity.

In passive immunotherapy, naked antibodies are administered to neutralize an antigen or to direct effector functions to targeted membrane associated antigens. Neutralization would be of a lymphokine, a hormone, or an anaphylatoxin, i.e., C5a. Effector functions include complement fixation, macrophage activation and recruitment, and antibody dependent cell mediated cytotoxicity (ADCC). Naked antibodies have been used to treat leukemia Ritz et al. S.F. Blood, (1981), 58, 141-152 and antibodies to GD2 have been used in treatments of neuroblastomas Schulz et al. Cancer Res. (1984), 44:5914 and melanomas Irie et al., Proc. Natl. Acad. Sci., (1986, 83:8694. Also, intravenous immune gamma globulin (IVIG) antibodies with high anti-RSV titers recently were used in experimental trials to treat respiratory

distress caused by RSV infection Hemming et al. Anti. Viral Agents and Chemotherapy, (1987), 31, 1882-1886, Groothuis et al., The New England J. Med. (1993), 329, 1524-1530, K. McIntosh. The New England J. Med. (1993), 329, 1572-1573, J. R. Groothuis. Antiviral Research, (1994), 23, 1-10, Siber et al. J. Infectious Diseases (1994), 169, 1368-1373.

The therapeutic efficacy of a monoclonal antibody depends on factors including, e.g., the amount, reactivity, specificity and class of the antibody bound to the antigen. Also, the *in vivo* half-life of the antibody is a significant therapeutic factor.

Still another factor which may significantly affect the therapeutic potential of antibodies is their species of origin. Currently, monoclonal antibodies used for immunotherapy are almost exclusively of rodent origin Schulz et al. Cancer Res. (1984), 44:5914, Miller et al. Blood (1981), 58, 78-86, Lanzavecchia et al. J. Edp. Med. (1988), 167, 345-352, Sikora et al. Br. Med. Bull. (1984), 40:240, Tsujisaki et al. Cancer Research (1991), 51:2599, largely because the generation of rodent monoclonal antibodies uses well characterized and highly efficient techniques Köhler et al. Nature, (1975), 256:495, Galfre et al. Nature, (1977), 266:550. However, while rodent monoclonal antibodies possess therapeutic efficacy, they can present restrictions and disadvantages relative to human antibodies. For example, they often induce sub-optimal stimulation of host effector functions (CDCC, ADCC, etc.). Also, murine antibodies may induce human anti-murine antibody (HAMA) responses Schroff et al. Can. Res. (1985, 45:879-885, Shawler et al. J. Immunol. (1985), 135:1530-1535. This may result in shortened antibody half-life Dillman et al. Mod. (1986), 5, 73-84, Miller et al. Blood, (1983), 62:988-995 and in some instances may cause toxic side effects such as serum sickness and anaphylaxis.

In some subjects, e.g., heavily immunosuppressed subjects (e.g., patients subjected to heavy chemical or radiation mediated cancer therapy Irie et al. Proc. Natl. Acad. Sci. (1986), 83:8694, Dillman et al. Mod. (1986), 5, 73-84, Koprowski et al. Proc. Natl. Acad. Sci. (1984), 81:216-219), use of murine monoclonal antibodies causes limited negative side effects. By contrast, in patients with normal

or hyperactive immune systems, murine antibodies, at least for some disease conditions may exhibit limited efficacy.

In an effort to obviate limitations of murine monoclonal antibodies, recombinant DNA techniques have been applied to produce chimeric antibodies Morrison et al. Proc. Natl. Acad. Sci. (1984), 81:216-219, Boulianne et al. Nature, (1984), 312, 644-646, humanized antibodies by "CDR grafting" Riechmann et al. Nature (1984), 332, 323-327 and "veneered" antibodies by substitution of specific surface residues with other amino acids to alleviate or eliminate antigenicity.

However, although such antibodies have been used successfully clinically Gillis et al. J. Immunol. Meth (1989), 25:191, they have proven cumbersome to produce. This is because the understanding of the requirements for optimal antigen recognition and affinity is not yet fully understood. Also, the human framework and the mouse CDR regions often interact sterically with a negative effect on antibody activity. Moreover, such antibodies sometimes still induce strong HAMA responses in patients.

Human antibodies present major advantages over their murine counterparts; they induce optional effector functions, they do not induce HAMA responses and host antigen-specific antibodies may lead to identification of epitopes of therapeutic value that may be too subtle to be recognized by a xenogeneic immune system Lennox et al, "Monoclonal Antibodies in Clinical Medicine," London: Academic Press (1982).

While human antibodies are highly desirable, their production is complicated by various factors including ethical considerations, and the fact that conventional methods for producing human antibodies are often inefficient. For example, human subjects cannot generally be adequately immunized with most antigens because of ethical and safety considerations. Consequently, reports of isolation of human monoclonal antibodies with useful affinities, $\geq 10^8$ molar to specific antigens are few McCabe et al. Cancer Research, (1988), 48, 4348-4353. Also, isolation of anti-viral human monoclonal antibodies from donor primed cells has proved to be unwieldy. For example, Gorny reported that only 7 of 14,329 EBV transformed cultures of peripheral blood mononuclear cells (PMBC's) from HIV positive donors resulted in stable, specific anti-HIV antibody producing cell lines Gorny et al. Proc. Natl. Acad. Sci. (1989), 86:1624-1628.

To date, most human anti-tumor antibodies have been generated from peripheral blood lymphocytes (PBLs) Irie et al. Br. J. Cancer, (1981), 44:262 or tumor draining lymph node lymphocytes Schlom et al. Proc. Natl. Acad. Sci. (1980), 77:6841-6845, Cote et al. Proc. Natl. Acad. Sci. (1983), 80:2026-2030 from cancer patients. However, such antibodies often react with intracellular, and thus therapeutically useless antigens Ho et al. In Hybridoma Technology. Amsterdam (1988), 37-57 or are of the IgM class McCabe et al. Cancer Research (1988), 48, 4348-4353, a class of antibodies with lesser ability to penetrate solid tumors than IgGs. Few of these human antibodies have moved to clinical trials Drobyski et al. R.C. Transplantation (1991), 51, 1190-1196, suggesting that the rescued antibodies may possess sub-optimal qualities. Moreover, since these approaches exploit the testing donor primed B cells, it is clear that these cells are not an optimal source for rescue of useful monoclonal antibodies.

Recently, generation of human antibodies from primed donors has been improved by stimulation with CD40 resulting in expansion of human B cells Banchereau et al. F. Science (1991), 251:70, Zhang et al. J. Immunol. (1990), 144, 2955-2960, Tohma et al. J. Immunol. (1991), 146:2544-2552 or by an extra *in vitro* booster step primer to immortalization Chaudhuri et al. Cancer Supplement (1994), 73, 1098-1104. This principle has been exploited to generate human monoclonal antibodies to Cytomegalovirus, Epstein-Barr Virus (EBV) and *Hemophilus influenza* with cells from primed donors (42-44), with a significantly higher yield than obtained with other methods (32).

Moreover, to address the limitations of donor priming, immunization and cultivation *ex vivo* of lymphocytes from healthy donors has been reported. Some success in generating human monoclonal antibodies using ex homine boosting of PBL cells from primed donors has been reported Maeda et al. Hybridoma (1986), 5:33-41, Kozbor et al. J. Immunol. (1984), 14:23, Duchosal et al. Nature (1992, 355:258-262. The feasibility of immunizing *in vitro* was first demonstrated in 1967 by Mishell and Dutton Mishell et al. J. Exp. Med (1967), 126:423-442 using murine lymphocytes. In 1973, Hoffman successfully immunized human lymphocytes Hoffman et al. Nature (1973), 243:408-410. Also, successful primary immunizations have been reported

with lymphocytes from peripheral blood Luzzati et al. J. Exp. Med. (1975), 144:573:585, Misiti et al. J. Exp. Med. (1981), 154:1069-1084, Komatsu et al. Int. Archs. Allergy Appl. Immunol. (1986), 80:431-434, Ohlin et al. C.A.K. Immunology (1989), 68:325 (1989) tonsils Strike et al. J. Immunol. (1978), 132:1789-1803 and spleens, the latter obtained from trauma Ho et al. In Hybridoma Technology, Amsterdam (1988), 37-57, Boerner et al. J. Immunol. (1991), 147:86-95, Ho et al. J. Immunol. (1985), 135:3831-3838, Wasserman et al. J. Immunol. Meth. (1986), 93:275-283, Wasserman et al. J. Immunol. Meth. (1986), 93:275-283, Brams et al. Hum. Antibod. Hybridomas (1993), 4, 47-56, Brams et al. Hum. Antibod. Hybridomas (1993), 4, 57-65 and idiopathic thrombocytopenia purpura (ITP) patients Boerner et al. J. Immunol. (1991), 147:86-95, Brams et al. Hum. Antibod. Hybridomas (1993) 4, 47-56, Brams et al. Hum. Antibod. Hybridomas (1993), 4, 57-65, McRoberts et al. "*In Vitro* Immunization in Hybridoma Technology", Elsevier, Amsterdam (1988), 267-275, Lu et al. P. Hybridoma (1993), 12, 381-389.

In vitro immunization offers considerable advantages, e.g., easily reproducible immunizations, lends itself easily to manipulation of antibody class by means of appropriate cultivation and manipulation techniques Chaudhuri et al. Cancer Supplement (1994), 73, 1098-1104. Also, there is evidence that the *in vivo* tolerance to self-antigens is not prevalent during IVI Boerner et al. J. Immunol. (1991), 147:86-95, Brams et al. J. Immunol. Methods (1987), 98:11. Therefore, this technique is potentially applicable for production of antibodies to self-antigens, e.g., tumor markers and receptors involved in autoimmunity.

Several groups have reported the generation of responses to a variety of antigens challenged only *in vitro*, e.g., tumor associated antigens (TAAs) Boerner et al. J. Immunol. (1991), 147:86-95, Borrebaeck et al. Proc. Natl. Acad. Sci. (1988), 85:3995. However, unfortunately, the resulting antibodies were typically of the IgM and not the IgG subclass McCabe et al. Cancer Research (1988), 48, 4348-4353, Koda et al. Hum. Antibod. Hybridomas, (1990), 1:15 and secondary (IgG) responses have only been reported with protocols using lymphocytes from immunized donors. Therefore, it would appear that these protocols only succeed in inducing a primary

immune response but require donor immunized cells for generation of recall responses.

Also, research has been conducted to systematically analyze cultivation and immunization variables to develop a general protocol for effectively inducing human monoclonal antibodies *in vitro* Boerner, J. Immunol. (1991) 147:86-95, Brams et al. Hum. Antibod. Hybridomas (1993), 4, 47-56, Lu et al. Hybridoma (1993), 12, 381-389. This has resulted in the isolation of human monoclonal antibodies specific for ferritin Boerner et al. J. Immunol. (1991), 147:86-95, induced by IVI of naive human spleen cells. Also, this research has resulted in a protocol by which *de novo* secondary (IgG) responses may be induced entirely *in vitro* Brams et al. Hum. Antibod. Hybridomas (1993), 4, 57-65.

However, despite the great potential advantages of IVI, the efficiency of such methods are severely restricted because of the fact that immune cells grow in monolayers in culture vessels. By contrast, *in vivo* germinal centers possessing a three-dimensional structure are found in the spleen during the active phases of an immune response. These three-dimensional structures comprise activated T- and B-cells surrounded by antigen-presenting cells which are believed by the majority of immunologists to compare the site of antigen-specific activation of B-cells.

An alternative to the natural splenic environment is to "recreate" or mimic splenic conditions in an immunocompromised animal host, such as the "Severe Combined Immune Deficient" (SCID) mouse. Human lymphocytes are readily adopted by the SCID mouse (hu-SCID) and produce high levels of immunoglobulins Mosier et al. Nature (1988), 335:256, McCune et al. L. Science (1988), 241, 1632-1639. Moreover, if the donor used for reconstitution has been exposed to a particular antigen, a strong secondary response to the same antigen can be elicited in such mice. For example, Duchosal et al. Duchosal et al. Nature (1992), 355:258-262 reported that human peripheral blood B-cells from a donor vaccinated with tetanus toxoid 17 years prior could be restimulated in the SCID environment to produce high serum levels, i.e., around 10^4. They further disclosed cloning and expression of the genes of two human anti-TT antibodies using the lambda and the M13 phage combinatorial library approach Huse et al. R.A. Science (1989), 246:1275 from the extracted human

cells. The reported antigen affinities of the antibodies were in the 10^8-10^9/M range. However, this protocol required donor primed cells and the yield was very low, only 2 clones were obtained from a library of 370,000 clones.

Therefore, previously the hu-SPL-SCID mouse has only been utilized for producing human monoclonal antibodies to antigens wherein the donor has either been efficiently primed naturally or by vaccination Stähli et al. Methods in Enzymology (1983), 92, 26-36, which in most cases involves exposure to viral or bacterial antigens. Also, the reported serum titer levels using the hu-SCID animal model are significantly lower than what is typically achieved by immunization of normal mice.

Additionally, two protocols have been described by which induction of primary antibody responses can be followed by induction of secondary antibody responses in hu-SCID mice using naive human lymphocytes. However, use of both of these protocols are substantially restricted. In the first protocol, primary responses are induced in hu-SCID mice into which human fetal liver, thymus and lymph nodes have been surgically implanted. However, this method is severely restricted by the limited availability of fetal tissue, as well as the complicated surgical methodology of the protocol McCune et al. L. Science (1988), 241, 1632-1639. In the second protocol, lethally irradiated normal mice were reconstituted with T- and B-cell depicted human bone marrow and SCID mouse bone marrow cells Lubin et al. Science, (1991), 252:427. However, this method is disadvantageous because it requires a four month incubation period. Moreover, both protocols result in very low antibody titers, i.e., below 10^4.

Also, Carlson et al. Carlsson et al. J. Immunol. (1992), 148:1065-1071 described in 1992 an approach using PBMCs from an antigen (tetanus toxoid) primed donor. The cells were first depleted of macrophages and NK cells before being subjected to a brief *in vitro* cultivation and priming period prior to transfer into a SCID mouse. The hu-SPL-SCID mouse was then boosted with antigen. This method was reported to result in average TT specific human IgG titers of $\simeq 10^4$ in the hu-SPL-SCID serum, with up to 5×10^5 reported.

Production of human monoclonal antibodies further typically requires the production of immortalized B-cells, in order to obtain cells which secrete a constant,

ideally permanent supply of the desired human monoclonal antibodies. Immortalization of B-cells is generally effected by one of four approaches: (i) transformation with EBV, (ii) mouse-human heterofusion, (iii) EBV transformation followed by heterofusion, and (iv) combinatorial immunoglobulin gene library techniques.

EBV transformation has been used successfully in a number of reports, mainly for the generation of anti-HIV antibodies Gorny, et al. Proc. Natl. Acad. Sci. (1989), 86:1624-1628, Posner, et al. J. Immunol. (1991), 146:4325-32. The main advantage is that approximately one of every 200 B-cells becomes transformed. However, EBV transformed cells are typically unstable, produce low amounts of mainly IgM antibody, clone poorly and cease making antibody after several months of culturing. Heterofusion Carrol, et al. J. Immunol. Meth. (1986), 89:61-72 is typically favored for producing hybridomas which secrete high levels of IgG antibody. Hybridomas are also easy to clone by limiting dilution. However, a disadvantage is the poor yield, i.e., $\leq$ 1 hybridomas per 20,000 lymphocytes Boerner, et al. J. Immunol. (1991), 147:86-95, Ohlin, et al. C.A.K. Immunology (1989), 68:325, Xiu-mei et al. Hum. Antibod. Hybridomas (1990), 1:42, Borrebaeck C.A.K. Abstract at the "Second International Conference" on "Human Antibodies and Hybridomas," April 26-28, 1992, Cambridge, England. Combining EBV transformation followed by heterofusion offers two advantages: (i) human B-cells fuse more readily to the fusion partner after EBV transformation, and (ii) result in more stable, higher producing hybridomas Ohlin, et al. Immunology (1989), 68:325, Xiu-mei, et al. Hum. Antibod. Hybridomas (1990), 1:42, Borrebaeck C.A.K. Absract at the "Second International Conference" on "Human Antibodies and Hybridomas," April 26-28, 1992, Cambridge, England. The advantage of the final technique, i.e., combinatorial immunoglobulin gene library technique is the fact that very large libraries can be screened by means of the M13 Fab expression technology Huse, et al. Science (1989), 246:1275, William Huse, Antibody Engineering: A Practical Guide, Borrebaeck C.A.K., ed. 5:103-120 and that the genes can easily be transferred to a production cell line. However, the yield is typically extremely low, on the order of 1 per 370,000 clones Duchosal, et al. Nature (1992), 355:258-262.

Thus, based on the foregoing, it is apparent that more efficient methods for producing human monoclonal antibodies, in particular antibodies specific to RSV, would be highly advantageous. Moreover, it is also apparent that human antibodies specific to the RSV F-protein having superior binding affinity, specificity and effector functions than those currently available would also be highly desirable.

OBJECTS OF THE INVENTION

It is an object of the invention to provide improved methods for producing human antibodies of high titers which are specific to desired antigens.

It is a more specific object of the invention to provide a novel method for producing high titer human antibodies which comprises (i) antigen priming of naive human splenocytes *in vitro*, (ii) transferral of *in vitro* antigen primed splenocyte cells to an immunocompromised donor, e.g., a SCID mouse, and (iii) boosting with antigen.

It is another specific object of the invention to provide improved methods for producing human monoclonal antibodies which are specific to respiratory syncytial virus (RSV), and in particular the RSV fusion (F) protein.

It is another object of the invention to provide an improved method for producing EBV immortalized B-cells which favors the formation of EBV immortalized B-cells which predominantly secrete IgG.

It is a more specific object of the invention to provide an improved method for producing EBV immortalized human B-cells which predominantly secrete IgG's which comprises:

(i) antigen priming of naive human splenocytes *in vitro*;

(ii) transferral of such *in vitro* antigen primed naive splenocytes to an immunocompromised donor, e.g., a SCID mouse;

(iii) boosting the immunocompromised donor with antigen;

(iv) isolation of human antibody producing B-cells from the antigen boosted immunocompromised donor, e.g., SCID mouse; and

(v) EBV transformation of said isolated human antibody producing B-cells.

It is another object of the invention to provide novel compositions containing EBV transformed human B-cells obtained from SCID mice which predominantly secrete human IgG's.

It is a more specific object of the invention to provide novel compositions containing EBV transformed human B-cells which predominantly secrete human IgG's produced by a method comprising:

(i) antigen priming of naive human splenocytes *in vitro*;

(ii) transferral of resulting *in vitro* antigen primed naive splenocytes to an immunocompromised animal donor, e.g., a SCID mouse;

(iii) boosting the immunocompromised animal donor, e.g., SCID mouse, with antigen;

(iv) isolation of human antibody producing B-cells from the antigen boosted immunocompromised donor, e.g., SCID mouse; and

(v) EBV transformation of said isolated human antibody producing B-cells.

It is another specific object of the invention to produce RSV neutralizing human monoclonal antibodies having an affinity to the RSV F-protein of $\leq 2 \times 10^{-9}$ Molar.

It is still another object of the invention to provide EBV immortalized cell lines which secrete RSV neutralizing human IgG monoclonal antibodies having an affinity to the RSV F antigen of $\leq 2 \times 10^{-9}$ Molar.

It is a more specific object of the present invention to provide two EBV immortalized cell lines, RF-2 and RF-1, which respectively secrete human monoclonal antibodies also referred to as RF-2 and RF-1 which neutralize RSV *in vivo* and each possess an affinity for the RSV F-protein of $\leq 2 \times 10^{-9}$.

It is another object of the invention to transfect eukaryotic cells with DNA sequences encoding the RF-1 or RF-2 heavy and light variable domains to produce transfectants which secrete human antibodies containing the variable domain of RF-1 or RF-2.

It is a more specific object of the invention to provide transfected CHO cells which express the RF-1 or RF-2 heavy and light variable domains.

It is another object of the invention to treat or prevent RSV infection in humans by administering a therapeutically or prophylactically effective amount of RSV neutralizing human monoclonal antibodies which are specific to the RSV F-protein and which exhibit a Kd for the RSV F-protein of $\leq 2 \times 10^{-9}$ molar.

It is a more specific object of the invention to treat or prevent RSV infection in humans by administering a therapeutically or prophylactically effective amount of RF-1 or RF-2 or a human monoclonal antibody expressed in a transfected eukaryotic cell which contains and expresses the variable heavy and light domains of RF-1 or RF-2.

It is another object of the invention to provide vaccines for treating or preventing RSV infection which comprise a therapeutically or prophylactically effective amount of human monoclonal antibodies specific to the RSV F-protein having a Kd for the RSV F-protein of $\leq 2 \times 10^{-9}$ molar, which neutralize RSV *in vitro*, in combination with a pharmaceutically acceptable carrier or excipient.

It is a more specific object of the invention to provide vaccines for treating or preventing RSV infection which comprise a therapeutically or prophylactically effective amount of RF-1 or RF-2 or human monoclonal antibodies derived from a transfected eukaryotic cell which contains and expresses DNA sequences encoding the variable heavy and light domains of RF-1 or RF-2, in combination with a pharmaceutically acceptable carrier or excipient.

It is another object of the present invention to provide a method for diagnosis of RSV infection by assaying the presence of RSV in analytes, e.g., respiratory fluids using human monoclonal antibodies which possess an affinity for the RSV fusion (F) protein or $\leq 2 \times 10^{-9}$ molar.

It is still another object of the invention to provide novel immunoprobes and test kits for detection of RSV infection which comprise human monoclonal antibodies specific to the RSV F-protein, which possess an affinity for the RSV F protein of $\leq 2 \times 10^{-9}$ molar, which antibodies are directly or indirectly attached to a suitable reporter molecule, e.g., an enzyme or a radionuclide. In the preferred embodiment these human monoclonal antibodies will comprise RF-1 or RF-2 or recombinant human monoclonal antibodies produced in eukaryotic cells, e.g., CHO cells, which are transfected with the variable heavy and light domains of RF-1 or RF-2.

BRIEF DESCRIPTION OF THE INVENTION

The present invention in its broadest embodiments relates to novel methods for making human antibodies to desired antigens, preferably antigens involved in prophylaxis, treatment or detection of a human disease condition. These methods comprise antigen priming of native human splenocytes *in vitro*, transferral of the resultant *in vitro* antigen primed splenocyte cells to an immunocompromised donor, e.g., a SCID mouse, and boosting said immunocompromised donor with antigen.

The present invention also relates to methods for producing Epstein-Barr Virus (EBV) immortalized B-cells which favors the production of cells which secrete IgGs comprising: antigen priming of naive human splenocytes *in vitro*; transferral of resultant *in vitro* antigen primed splenocytes to an immunocompromised donor, e.g., a SCID mouse; boosting the immunocompromised donor with antigen; isolating human antibody secreting B-cells, preferably IgG secreting, from the antigen boosted immunocompromised donor, e.g., SCID mouse; and EBV transformation of said isolated human antibody secreting cells.

The present invention more specifically relates to improved methods for making human antibodies to RSV, in particular the RSV fusion (F) protein which exhibit high affinity to RSV F-protein and which also neutralize RSV infection, as well as the human monoclonal antibodies which result from these methods. This is preferably effected by priming of naive human splenocytes *in vitro* with Il-2 and optionally the RSV F-protein; transferral of the resultant *in vitro* primed splenocyte cells to an immunocompromised donor, e.g., a SCID mouse, and boosting with RSV F-protein to produce human B-cells which secrete neutralizing anti-RSV F-protein human antibodies having high affinity to the RSV F-protein, i.e., $\leq 2 \times 10^{9}$ molar.

The resultant B-cells are preferably immortalized so as to provide a constant stable supply of human anti-RSV F-protein monoclonal antibodies. In the preferred embodiment B-cells are isolated from the antigen boosted SCID mouse and transformed with EBV virus to produce EBV transformed human B-cells which predominantly secrete human IgGs.

These cells are then cloned to select EBV transformed cell lines which secrete human monoclonal antibodies having high affinity to RSV F-protein, i.e. $\leq 10^{-7}$ and preferably $\leq 2 \times 10^{-9}$ molar.

The present invention also relates to the use of such anti-RSV F-protein human monoclonal antibodies as therapeutic and/or prophylactic, as well as diagnostic agents. As noted, the subject methods result in the generation of human monoclonal antibodies which exhibit high affinity to the RSV F-protein, i.e., which possess a Kd for the RSV F-protein of $\leq 2 \times 10^{-9}$ molar, which also neutralize RSV *in vitro*. Therefore, these antibodies are ideally suited as prophylactic and therapeutic agents for preventing or treating RSV infection given the fact that the RSV F-protein is a surface protein which is highly conserved across different RSV isolates. Also, given the high affinity and specificity of the subject human monoclonal antibodies to RSV F-protein, they also may be used to diagnose RSV infection.

More specifically, the present invention provides two particular human monoclonal antibodies to the RSV F-protein, i.e., RF-1 and RF-2, as well as recombinant human antibodies derived therefrom, which are preferably produced in CHO cells, which cells have been transfected with DNA sequences encoding the variable heavy and light domains of RF-1 or RF-2. These antibodies are particularly useful as prophylactic and/or therapeutic agents for treatment or prevention of RSV infection. Moreover, these antibodies are useful as diagnostic agents because they bind the RSV F-protein with high affinity, i.e., each possess affinity for the RSV F-protein of $\leq 2 \times 10^{-9}$. They are especially useful as therapeutic agents because of their high affinity and specificity for the RSV F-protein, and their ability to effectively neutralize RSV infection *in vitro*.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 depicts immunoblot of F protein with anti-F protein hu-SPL-SCID sera: Notice (A) and denatured (B) F protein was run in SDS-PAGE and transferred to nitrocellulose by Western blot. Nitrocellulose strips were reacted with positive control mouse anti-F protein MAb (lanes 1A and 1B), negative control hu-SPL-SCID

serum anti-TT (lanes 2A and 2B) and hu-SPL-SCID anti-F protein sera from mice #6 (lanes 3A and 3B), #3 (lanes 4A and 4B) and #4 (lanes #5A and 5B).

Figure 2 depicts immunofluorescence of HEP-2 cells with hu-SPL-SCID sera anti-F protein. Uninfected (left) and RSV-infected HEp-2 cells were reacted with serum from hu-SPL-SCID mouse #6 diluted 1:50 taken 15 days after boost. Binding was revealed GAH IgG-FITC.

Figure 3 depicts the reactivity of purified RF-1 and RF-2 to plastic bound affinity purified RSV F-protein. The reactivity of a reference human anti-RSV serum, LN, is also recorded. The ELISA plate was coated with 50 ng RSV F-protein.

Figure 4 depicts IEF of RF-1 (lane 2) and RF-2 (lane 3) human MAb purified from tumor cell supernatants. IEF was performed on a pH gradient of 3-10. Lane 1 represents the pi standards.

Figure 5 depicts indirect Immunofluorescence flow cytometry assay of HEp-2 cells and HEp-2-cells infected with RSV, $1x10^6$, incubated with various amounts of RF-1 and subsequently with a FITC-labeled GAH IgG. The relative average intensity of the entire population is recorded.

Figure 6 depicts NEOSPLA vector used for expression of human antibodies. CMV = cytomegalovirus promoter. BETA = mouse beta globin major promoter. BGH = bovine growth hormone polyadenylation signal. SVO = SV40 origin of replication. N1 = Neomycin phosphotransferase exon 1. N2 = Neomycin phosphotransferase exon 2. LIGHT = Human immunoglobulin kappa constant region. Heavy = Human immunoglobulin gamma 1 or gamma 4 PE constant region. L = leader. SV = SV40 polyadenylation region.

Figure 7a depicts the amino acid and nucleic acid sequence of the variable light domain of RF-1.

Figure 7b depicts the amino acid and nucleic acid sequence of the variable heavy domain of RF-1.

Figure 8a depicts the amino acid and nucleic acid sequence of the variable light domain of RF-2.

Figure 8b depicts the amino acid and nucleic acid sequence of the variable heavy domain of RF-2.

Figure 9a depicts the amino acid and nucleic acid sequence of the RF-1 light chain, the leader sequence, and the human kappa constant domain sequence.

Figure 9b depicts the amino acid and nucleic acid sequence of the RF-1 heavy chain, a leader sequence, and the human gamma/constant domain sequence.

Figure 9a depicts the human constant domain sequence.

Figure 10 depicts schematically the NEOSPLA vector, referred to as NSKE1 containing the RF-1 nucleic acid sequence and human gamma/constant domain set forth in Figures 9a-9c.

Figure 11a depicts the amino acid and nucleic acid sequence of the RF-2 light chain, leader sequence, and human Kappa constant domain.

Figure 11b depicts the amino acid and nucleic acid sequence of the RF-2 heavy chain, leader sequence, and human gamma/constant domain.

Figure 11c depicts the amino acid and nucleic acid sequence of the human gamma/constant domain.

Figure 12 depicts schematically the NEOSPLA expression vector, referred to as NSKG1 containing the RF-2 nucleic acid sequences and human gamma/constant domain sequences set forth in Figures 11a-11c.

DETAILED DESCRIPTION OF THE INVENTION

As discussed, the present invention provides a novel highly efficient method for producing human monoclonal antibodies to desired antigens, preferably antigens which are involved in a human disease condition. Antigens involved in a human disease condition typically will be surface antigens which comprise suitable therapeutic targets for antibodies. For example, this includes surface proteins of viruses and antigens expressed on the surface of human cancer cells. In the preferred embodiment, the surface antigen will comprise the fusion protein (F-protein) of RSV.

Human disease conditions includes by way of example viral infections, e.g., RSV, papillomavirus, hepatitis, AIDS, etc., cancer, bacterial infections, yeast infections, parasite infection, e.g, malaria, etc. Essentially, human disease conditions are intended to embrace any human disease condition potentially preventable or

treatable by the administration of human monoclonal antibodies specific to a particular antigen.

The subject method for producing human monoclonal antibodies essentially involves the combination of *in vitro* priming of naive human spleen cells, transferral of these spleen cells to immunocompromised donors, i.e., SCID mice, followed by antigen boosting of SCID mice which have been administered said spleen cells. It has been surprisingly discovered that the combination of these two known methods for producing human antibodies results in synergistic results. Specifically, it results in very enhanced antigen specific responses to the immunizing antigen as well as very high titers of human monoclonal antibodies of the IgG isotype. More specifically, it has been found that this combination results in unprecedented high secondary responses: the human IgG responses in the hu-SPL-SCID serum were 10-fold higher than those resulting from transfer of naive cells in SCID and specific antibody responses were 1000-fold increased. Also, the resulting antibodies are found to be of high affinity and specificity comparable to antibodies produced in experimentally hyperactive immune animals. It has also been found that when using naive spleen cells, to obtain such unexpected results it is necessary to challenge with antigen both *in vitro* and after introduction into the resultant hu-SPL-SCID mouse. Also, it is preferable but not essential to introduce additional fresh non-primed spleen cells to the hu-SPL-SCID donor just prior to antigen boosting. This has been found to result in still further enhancement of the antibody response.

The present invention was developed after an optimal *in vitro* primary and boosting protocol for the generation of secondary responses from naive human spleen cells had previously been disclosed Brams et al. Hum. Antibod. Hybridomas (1993), 4, 57-65. The protocol Brams et al. Hum. Antibod. Hybridomas (1993), 4, 57-65 was found to provide for antigen specific IgG responses about 2 to 10 times higher than obtained from cultures subjected to one antigen challenge. This *in vitro* immunization (IVI) protocol was developed and optimized using very different antigens, i.e., horse ferritin (HoF), calmodulin, prostate specific antigen (PSA), mouse IgG, transferrin, Keyhole Limpet Hemocyanine (KLH) di-nitro phenyl (DNP) bound to T-cell dependent protein carriers and RSV fusion (F) protein.

Essentially, this protocol involves restimulation of the spleen cell culture on day 1 after culturing is started with antigen together with autologous spleen cells in a 1:1 ratio. It has been demonstrated that the IgG responses measured using this protocol were the result of repeated antigen exposure, and are equivalent to secondary responses.

These experiments further demonstrated that intact spleens were the optimal source of lymphocytes, including trauma- and ITP spleens. By contrast, peripheral blood lymphocytes (PBLs), and cells from tonsils or lymph nodes proved to be inferior for induction of antigen-specific responses. Moreover, depletion or neutralization of any cellular component resulted in inferior responses Boerner et al. J. Immunol. (1991), 147:86-95. Also, these experiments indicated that for a given spleen cell preparation and antigen, that there exists a unique optimal antigen concentration.

Therefore, having established an optimal *in vitro* primary and boosting protocol for generation of secondary responses from naive human spleen cells; it was conceived to test this protocol in combination with previous *in vivo* methods for producing human monoclonal antibodies, i.e., the SCID mouse. It was unknown prior to testing what effect, if any, administration of antigen primed spleen cells would have on the resultant production of human monoclonal antibodies to a given antigen by the SCID mouse or the ability of human lymphocytes to be maintained therein. However, it was hoped that this would provide for enhanced antigen boost and enhanced expression of the *in vitro* antigen primed naive spleen cells.

In this regard, it has been previously reported that human lymphocytes can establish themselves and remain alive for several months in SCIDs McCune et al. Science (1988), 241, 1632-1639, Lubin et al. Science (1991), 252:427. However, as noted, surpa previous methods using SCIDs or human monoclonal antibodies to antigens have used cells from donors previously exposed to the antigen either naturally or by vaccination and have typically not resulted in high human antibody titers.

Quite surprisingly, it was found that combination of *in vitro* primary and boosting protocol for generation of secondary responses from human naive spleen

cells Brams et al. Hum. Antibod. Hybridomas (1993), 4, 57-65 in the hu-SCID model resulted in synergistic results as evidenced by highly significant antigen specific IgG responses to the immunizing antigen.

Further, it was also discovered that the combination of these methods (using horse ferritin (HoF) as a model antigen) that:

(i) introduction of an *in vitro* immunization step prior to transfer into SCIDs is essential for reliably inducing significant antigen-specific responses;

(ii) human cells must be transferred into the peritoneum to achieve optional maintenance of human splenocytes in the SCID mouse;

(iii) optimal *in vitro* cultivation is about three days;

(iv) use of IL-2 and optionally IL-4 or IL-6 *in vitro* results in highest antibody titers of antigen specific responses in the hu-SPL-SCID mice;

(v) the hu-SPL-SCID in mouse is preferably boosted with antigen emulsified in an adjuvant, e.g., Freunds Complete Adjuvant (FCA) and/or Alum;

(vi) killing or neutralization of NK cells, whether of murine or human origin surprisingly has no benefit on antibody production. However, it was found that use of the SCID-beige mouse, an NK low line, as the host for the *in vitro* primed cells, provides for a superior response when boosting is effected using a combination of adjuvants, i.e., FCA and Alum.

(vii) spleens, but not lymph nodes of $\simeq$ ⅓ of the hu-SPL-SCID mice were enlarged up to 25 times compared to normal SCIDs. Moreover, of these up to two-thirds of the cells in such spleens tested positive for normal human lymphocyte membrane markers.

More specifically, the subject method comprises priming naive human splenocytes *in vitro*, for about 1 to 10 days, preferably about 3 days with antigen, transferral of the primed cells to a SCID mouse, and subsequently boosting the mouse with antigen about 3 to 14 days later, preferably about 7 days later. This has been demonstrated to result in high antigen specific IgG responses in the sera of the resultant hu-SPL-SCID mouse from about day 24 onwards. Typically, the serum end-dilution titers are about 10^6 (half maximal responses at approximately 50 mg IgG/ml) using a naive antigen, horse ferritin and 10^7 (half maximal responses at approximately

5 mg IgG/ml) when a recall response is induced with a viral antigen, i.e., the fusion protein of RSV. It is expected based on these results that similar responses will be obtained using other antigens.

As noted, optimal induction of the desired antibody response requires antigen challenge of the human cells both *in vitro* and *in vivo* in the hu-SPL-SCID mouse. It was also found that IL-2 is necessary during *in vitro* priming, and that IL-4 and IL-6 administered concomitantly with IL-2 further enhanced responses in the hu-SPL-SCID mouse. Moreover, SCID reconstitution is facilitated but was not dependent on concomitant intraperitoneal administration of irradiated allogeneic lymphocytes.

It was further discovered that there was significant variation in the antibody responses from one spleen to another. For example, some spleens required concomitant administration of antigen and fresh autologous spleen cells on day 10 for generation of antigen specific antibody responses. Also, it was found that the level of antibody responses varied somewhat in different hu-SPL-SCID mice. However, based on the teachings in this application, one skilled in the art can readily select suitable conditions so as to produce an optimal antigen specific antibody response to a given antigen.

For example, by testing several different spleen preparations for their ability to produce specific antibody in culture, e.g., after ten days of *in vitro* immunization, one can identify the highest responder. Moreover, since large numbers of cells are prepared and frozen from each spleen, it is possible to set up a new *in vitro* immunization for three days from the selected spleen and follow up with transfer in SCID mice. By contrast, other cellular materials, e.g., peripheral blood cells are not amenable to such optimization, given the fairly limited amount of PBL's recoverable from one donor in a single transferral.

As previously noted, in contrast to previous reports, it was found that for the present method, when peripheral blood cells were used, neutralization of human NK activity had no effect on spleens. Moreover, neutralization of SCID NK cells with complement fixing anti-asialo GMI antibodies decreased antigen-specific IgG responses. By contrast, use of the SCID/beige mouse, a strain with reduced NK cell

levels did provide for significantly increased antigen specific IgG responses compared to normal SCID.

Additionally, two immunization routes, intravenous (IV) and intraperitoneal (IP) were compared for their ability to provide for reconstitution of SCID mice, i.e., maintenance of spleen cells therein and the production of human antibodies. It was found that the peritoneum was the optimal site of cell transfer and immunization. Moreover, date, transfer of cells intravenously has never been found to result in repopulation when more than 0.01 μg/ml human IgG was detected in the mouse serum.

It was also found that the resultant IgG concentrations directly correlated with the number of transferred human cells. For example, repopulation of SCIDs was 92% when 5 x 10^6 *in vitro* primed spleen cells were injected intraperitoneally, and virtually 100% when 5 x 10^7 *in vitro* primed spleen cells were injected intraperitoneally. One skilled in the art can, based on the teachings in this application, select an optimal number of injected *in vitro* primed spleen cells. In general, this will range from about 10^4 to about 10^8 cells, more preferably about 10^6 to 10^8 cells, and most preferably at least about 10^7 to 10^8 cells.

It was also found that the antibody response is affected by the presence of the particular adjuvant. More specifically, it was observed that maximal human antibody responses were achieved when the hu-SPL-SCID mice were boosted with antigen emulsified in Complete Freund's adjuvant (CFA) or using CFA and Alum together. Tests in hu-SPC-SCID boosted with ferritin showed that CFA was a better adjuvant than Alum, eliciting 33 mg and 13 mg/ml human IgG respectively. Combination of CFA and Alum did not improve response in SCID. However, use of these adjuvants in SCID/beige-hu (which mice comprise a mutation resulting in reduced NK cell activity) results in 8-10 fold increase in IgG production compared to CFA alone. However, it is expected that other adjuvants, or combinations thereof, may also produce similar or even enhanced results. The highest total human IgG concentrate using Complete Freund's adjuvant and Alum together was about 10 mg/ml, and the specific highest IgG concentration was about 500 μg/ml monoclonal antibody equivalent.

Using this method with ferritin produced polyclonal antibody responses comparable to that obtained in hyperimmune goats, rabbits and pigs in terms of specificity, reactivity, and use of Ig chain isotypes. The hu-SPL-SCID serum antibodies were mostly IgG, bound only to cells from tissues high in ferritin, and not to cells from ferritin-low or ferritin-negative tissues, and recognized both natural ferritin as well as denatured ferritin in a Western blot. These results are extremely unexpected both in antibody concentration and the antigen specificity of human antibodies obtained. Moreover, similar results are obtained using different antigens.

After injection, it is found that human cells tend to accumulate at two sites, i.e., the peritoneum and the mouse spleen. While no more than about 7% of human cells were found in the blood, the lymph nodes and the liver were of human antigen, between 25% and 33% of the cells were of human origin in enlarged spleens and in the occasional tumors in some animals. These human cells were almost exclusively B and T-cells, with a small amount of $CD14^+$ cells, mostly monocytes, in the enlarged spleens.

These results were determined by flow cytometry investigating spleen, lymph nodes, liver and peritoneum. In those cases that the human splenocytes repopulated the spleen, it was found that the spleens were often enlarged, up to 25 times the size of native SCID spleens. The human cells constituted up to about 30% of the total number of cells in the spleen when measured immediately after extraction, with the remainder of unknown origin. However, after 3 days in culture, a majority of surviving cells were found to be of human origin as the cells bound antibodies and exhibited no cross reactivity with mouse lymphocytes.

It was further observed that the reconstituted mice could be divided into two groups, those with normal size spleens and those with enlarged spleens. Hu-SPL-SCID mice with enlarged spleens, i.e., 25 times normal size had human IgG levels approximately 150 times higher than those with normal spleens, and the level of antigen specific human IgG was approximately 10,000 higher in those with normal size spleens which were treated similarly. It was also found that the relative affinity of the antigen specific response increased throughout the response, indicating that a higher percentage of the total immunoglobulin pool was comprised of antibodies

having better binding properties. These results indicate that the system is antigen driven.

These results are highly significant and indicate that it should generally be possible to rescue human cells from the hu-SPL-SCID and use same for generating combinatorial human antibody gene libraries thereby resulting in human monoclonal antibodies of high affinity and specificity that may be used clinically and/or diagnostically.

More specifically, the present invention provides novel human monoclonal antibodies to the RSV F-protein which exhibit high affinity to the RSV F-protein, i.e., $\leq 2 \times 10^{-9}$ molar protein and which human monoclonal antibodies are capable of neutralizing RSV *in vitro*. The present invention further provides methods for manufacture of such human monoclonal antibodies to the RSV F-protein.

In general, such human antibodies are produced by *in vitro* immunization of naive human splenocytes with RSV F-protein, transferral of such *in vitro* immunized human splenocytes into an immunocompromised animal donor, i.e., a SCID mouse, boosting said animal with RSV F-protein, and isolation of human B cells therefrom which secrete human monoclonal antibodies to the RSV F-protein, immunization of said human B cells, and cloning of said immunilized B cells to select cells which secrete human monoclonal antibodies having a high affinity to RSV F-protein, preferably at least 10^{-7} molar and more preferably $\leq 2 \times 10^{-9}$ molar.

As discussed, it has been discovered that the combination of *in vitro* immunization, in particular of human splenocytes, i.e., which have or have not been previously exposed to the RSV F-antigen and transferred to an immunocompromised animal donor, i.e., SCID mouse which is then boosted with RSV F-protein antigen affords significant advantages relative to conventional methods for making human antibodies in SCID mice. Namely, it provides for very high antibody titers, i.e., the highest anti-F protein titers being about 10^{-7}, high IgG concentrations, i.e., about 3 mg/ml for the highest responders. Moreover, this method allows for the production of human antibodies having highly advantageous combinations of properties, i.e., which exhibit both high affinity to the RSV F-protein and which moreover display substantial *in vitro* neutralizing activity.

As described in greater detail in the examples, the present inventors have isolated two human monoclonal antibodies, RF-1 which exhibits an affinity constant Ka to the F-protein, Ka = 10^{10} M when determined by plasmon resonance, and RF-2 which exhibits an affinity constant of Ka = 5 x 10^{8} M when determined by titration microcolorimetry. Also, the calculated Kd of RF-2 was 2 x 10^{-9} M. Moreover, both of these antibodies display *in vitro* virus neutralizing properties at concentrations of between 8 and 120 ng/ml as well as exhibiting an ability to inhibit the fusion of previously RSV infected cells. Significantly, this *in vitro* neutralization activity is applicable against a broad variety of different wild and laboratory RSV strains, both of the A and B virus types.

Given these results, i.e. the high affinity of the subject antibodies to the RSV F-protein, which comprises a surface protein expressed on the surface of RSV infected cells, as well as ability to effectively neutralize the virus, and to inhibit fusion of virally infected cells, the subject human monoclonal antibodies should be suitable both as therapeutic and prophylactic agents, i.e., for treating or preventing RSV infection in susceptible or RSV infected subjects. As noted, RSV infection is particularly prevalent in infants, as well as in immunocompromised persons. Therefore, the subject monoclonal antibodies will be particularly desirable for preventing or treating RSV infection in such subjects.

Moreover, given the human origin of the subject monoclonal antibodies, they are particularly suitable for passive immunotherapy. This is because they likely will not be subject to the potential constraints of murine monoclonal antibodies, i.e., HAMA responses and absence of normal human effector functions. In fact, based on the characterization of the subject human monoclonal antibodies (described in examples *infra*), it would appear that both RF-1 and RF-2 exhibit substantially greater *in vitro* neutralization activity and ability to inhibit fusion of previously infected RSV cells than previously disclosed murine or chimeric anti-F protein antibodies and human Fab fragments derived from recombinational libraries. Also, given their human origin it is expected that such neutralization activity will be maintained upon *in vivo* administration.

Another advantage of the subject human monoclonal antibodies is their substantial absence of reactivity with normal tissues. As shown *infra*, the subject human monoclonal antibodies bind only to RSV infected cells, not to cell lines representing lymphoid tissue, liver, prostrate or laryngeal epidermis. Therefore, these antibodies upon *in vivo* administration should efficiently bind to RSV infected cells and not to normal tissues and thereby should provide for neutralization of RSV infection. Further, based on the disclosed properties, it is expected that the subject human monoclonal antibodies to the RSV F-protein may be used to protect susceptible hosts against RSV infection.

More specifically, the subject human monoclonal antibodies to the RSV F-protein are produced by obtaining human splenocytes, e.g., from a trauma or ITP source, which are then primed *in vitro*. This essentially comprises culturing said naive human splenocytes *in vitro* in the presence of a sufficient amount of Il-2 and optionally RSV F-protein to induce immunization, also referred to as antigen priming. In general, the amount of RSV F-protein that may be used ranges from about 1 to 200 ng/ml RSV protein, more preferably 10 to 100 ng/ml, and most preferably about 40 ng/ml of RSV F-protein.

The *in vitro* culture medium will preferably also contain lymphokines, in particular IL-2 and optionally IL-4 and IL-6. The amount thereof will be amounts which provide for immunization and the desired production of antibody producing cells. For example, in the case of IL-2, an amount ranging from about 5 to 200 IU/ml, and more preferably from about 10 to 50 IU/ml, most preferably 25 IU/ml is suitable.

This culture medium will also contain other constituents necessary to maintain the viability of human splenocytes in culture, e.g., amino acids and serum. In the examples, a culture medium containing IMDM supplemented with 2mM glutamine, 2mM sodium pyruvate, non-essential amino acids, 25 IU/ml IL-2 and 20% fetal calf serum was used. However, one skilled in the art, based on the teachings in this application, can vary the culture medium using routine optimization.

The *in vitro* immunization step will be effected for a time sufficient to induce immunization. In general, the cells will be cultured in the presence of RSV F-protein

from about 1 to 10 days and preferably for about 3 days. However, this will vary dependent, e.g., upon the particular spleen sample. Similarly, one skilled in the art, based on the teachings in this application and using known methods may determine a suitable duration for the *in vitro* immunization step.

The antigen used for the *in vitro* immunization will preferably be a purified RSV F-protein so as to ensure that the splenocytes are immunized against the F-protein and not against other useless (non-surface) antigens. Methods for obtaining purified RSV protein are known in the art. The present inventors in particular utilized the method of Walsh et al. *J. Gen Virol.*, 70, 2953-2961, 1989. However, the particular method is not critical provided that RSV F-protein of sufficient purity to obtain human monoclonal antibodies having specificity to the RSV F-protein are obtained. Alternatively, the RSV F-protein may be produced by recombinant methods as described in U.S. Patent No. 5288630 issued on February 22, 1994.

After *in vitro* immunization, the RSV F-protein immunized or primed naive human splenocytes are then introduced into an immunocompromised donor, i.e., a SCID mouse. This is preferably effected by intraperitoneally administering the RSV F-protein primed human splenocytes into SCID mice. The number of such splenocytes which is administered will typically vary from about 10^4 to 10^8 spleen cells, with about 10^7 to 10^8 spleen cells being preferred. The number of such cells is that which results in the desired reconstitution, i.e., SCID mice which produce recoverable concentrations of human antibodies specific to the RSV F-protein. Preferably, such spleen cells will be suspended in HBSS at a concentration of about 8×10^8 cells/ml prior to administration.

After intraperitoneal transferral of splenocytes, the SCID mice are then boosted with the RSV F-protein. This is effected at a time sufficiently proximate to the transferal of splenocytes such that the desired production of human anti-RSV F-protein antibodies is realized. In general, this may be effected 3 to 14 days after transferral, and optimally about 7 days after transferral. Preferably, said antigen administration will be effected intraperitoneally. The amount of RSV F-protein administered will range from about 1 to 50 μg and preferably about 1 to 10 μg. In the examples, 5 μg protein was administered. However, the amount and time of

immunization may vary dependent upon the particular mouse, spleen sample, and purity of RSV F-protein.

Preferably, antigen boosting will be effected in the presence of an adjuvant, e.g., Complete Freund's Adjuvant, Alum, Saponin, etc., with Complete Freund's Adjuvant (CFA) and Alum being preferred. However, it is expected that other known adjuvants may be substituted to obtain substantially equivalent or even enhanced results.

After antigen boosting, the SCID mice are then bled, e.g., tail bled, and their serum tested for human IgG concentration and anti-F protein antibody titers. Those animals which exhibit the highest antibody titers and concentration are then used for recovery of human IgG secreting cells.

It has been discovered that SCID mice having the highest anti-F human antibody titers developed large abdominal tumors which provide a good source of human antibody secreting cells. Preferably, these tumors are recovered by excision under sterile conditions, single cell suspensions are prepared, and the cells are then washed and cultured. In the examples, the cells are washed with IMDM containing 2% fetal calf serum, and the cells cultured in suspension of 10^6 cells/ml in T-25 flasks containing IMDM with 10% FCS. However, such culturing conditions may be varied by one skilled in the art.

These cells are then immortalized preferably using EBV. Immortalized cells which secrete anti-F protein antibodies are then identified by known methods, e.g., ELISA. As noted, this method has been demonstrated to result in the identification of two distinct human monoclonal antibodies which specifically bind RSV F-protein, i.e. RF-1 and RF-2. However, based on the teachings in their application, in particular the examples, other human monoclonal antibodies to the RSV F-protein having similar properties may be obtained by one skilled in the art absent undue experimentation. These antibodies are distinct given the fact that most were generated in two different experiments, using different SCID mice. The cell lines which express RF-1 and RF-2 have been maintained in culture for prolonged time, i.e., about 18 and 16 months respectively; dividing with an approximate doubling time of about 36-48 hours. The

specific antibody concentration is on average about 0.8 - 1 μg/ml in a culture seeded at 0.5 x 10^6 cells/ml grown for three days.

As discussed in greater detail *infra*, both RF-1 and RF-2 are IgG (1, k) with half-maximal binding to F-protein in ELISA at 0.6 and 1 ng/ml respectively, and exhibiting isoelectric points of about 8.8 and 8.9 respectively.

Moreover, these antibodies exhibit high affinity to the RSV F-protein. Specifically, for RF-1 the dissociation constant for RF-1 as determined by plasmon resonance on an IASYS machine is about 10^{-10} M. The Ka constant for RF-2 is similarly high; when determined by titration microcolorimetry according to Wiseman et al. (1989) and Robert et al. (1989) it is about 2 x 10^9 M.

Additionally, these antibodies have been demonstrated to effectively bind RSV infected cells, while not binding normal human cells tested, e.g., respiratory tract lining (HEp-2, a laryngeal epidermoid carcinoma, CCL 23), liver (HepG2, a human hepatoma cell line, HB 8068), lymphoid tissue, SB, a human B lymphoblastoid cell line, cat. no. CCL 120 and HSB, a T lymphoblastoid line, cat. no. CCL 120.1, and prostrate (LNCaP.FGC, a human prostrate adenocarcinoma line, cat. no. CRL 1740).

Significantly, both RF-1 and RF-2 both have been shown to exhibit substantial *in vitro* RSV viral neutralization. This was demonstrated in two different assays (described in greater detail *infra*), i.e., an infection neutralization assay effected by pre-reacting the virus with purified monoclonal antibody prior to its addition to cells (which measures ability of antibody to inhibit virus infectivity) and a fusion inhibition assay which measures the ability of the monoclonal antibody to inhibit virus growth and expansion after virus entry into the cell.

Moreover, as discussed in greater detail *infra*, both RF-1 and RF-2 inhibited virus infection of twelve different isolates at concentrations respectively ranging from about 30 ng/ml to 1000 ng/ml. Thus, RF-2 apparently performs better than RF-1, yielding to 50% virus inhibition (ED50) at concentrations which are about 1.25 to 10 times lower than RF-1.

By contrast, higher concentrations of monoclonal antibody are required to inhibit fusion and viral antigen expression in previously infected cells, with RF-1 being about 5 to 10 times more potent than RF-2. Moreover, both RF-1 and RF-2

were effective against a Type B RSV, Type B prototype RS 6556, and a Type A RSV, Type A prototype RS Long. Thus, the *in vitro* results indicate that the subject human monoclonal antibodies may be used to treat or prevent RSV infection caused by different RSV strains, both of Type A and Type B prototype. As discussed previously, the RSV F-protein is fairly well conserved in different RSV isolates. Therefore, it is likely that the subject monoclonal antibodies to the RSV F-protein bind to a conserved epitope of RSV F-protein.

As discussed, the subject human monoclonal antibodies or recombinant human antibodies containing the variable heavy and light sequences therefrom (preparation discussed *infra*) will be used as therapeutic and prophylactic agents to treat or prevent RSV infection by passive antibody therapy. In particular, the DNA sequence encoding these DNA variable domains may be incorporated in IDEC's proprietary expression vector which is depicted in Figure 2. This version is substantially described in commonly assigned U.S. Serial No. 08/379,072, filed on January 25, 1995, herein incorporated by reference. This vector constant human constant domain, for example, human gamma 1, human gamma 4 or a mutated form thereof referred to as gamma 4 PE. (See U.S. Serial No. 08/379,072, incorporated by reference herein.) In general, this will comprise administering a therapeutically or prophylactically effective amount of the subject human monoclonal antibodies to a susceptible subject or one exhibiting RSV infection. A dosage effective amount will preferably range from about 50 to 20,000 μg/Kg, more preferably from about 100 to 5000 μg/Kg. However, suitable dosages will vary dependent on factors such as the condition of the treated host, weight, etc. Suitable effective dosages may be determined by those skilled in the art.

The subject human monoclonal antibodies may be administered by any mode of administration suitable for administering antibodies. Typically, the subject antibodies will be administered by injection, e.g., intravenous, intramuscular, or intraperitoneal injection, or more preferably by aerosol. As previously noted, aerosol administration is particularly preferred if the subjects treated comprise newborn infants.

Formulation of antibodies in pharmaceutically acceptable form may be effected by known methods, using known pharmaceutical carriers and excipients. Suitable carriers and excipients include by way of example buffered saline, bovine serum albumin, etc.

Moreover, the subject antibodies, given their high specificity and affinity to RSV infected cells possess utility as immunoprobes for diagnosis of RSV infection. This will generally comprise taking a sample, e.g. respiratory fluid, of a person suspected of having RSV infection and incubating the sample with the subject human monoclonal antibodies to detect the presence of RSV infected cells.

This will involve directly or indirectly labeling the subject human antibodies with a reporter molecule which provides for detection of human monoclonal antibody - RSV immune complexes. Examples of known labels include by way of example enzymes, e.g. ß-lactamase, luciferase, etc. and radiolabels.

Methods for effecting immunodetection of antigens using monoclonal antibodies are well known in the art. Also, the subject anti-RSV F-protein antibodies in combination with a diagnostically effective amount of a suitable reporter molecule may be formulated as a test kit for detection of RSV infection.

MATERIALS AND METHODS

The following Materials and Methods were used in Examples 1 to 6.

F protein preparation and purification:

F protein was prepared essentially according to the method of Walsh et al. *J. Gen. Virol*, 70, 2953-2961, (1989). Briefly, HEp-2 cells at 70% confluency were infected with the Long strain of RSV, a lab adapted strain of the A type. After culture for 48 hours in T-150 culture flasks in IMDM supplemented with 5% fetal calf serum, 2 mM glutamine and 2 mM sodium pyruvate, the cells were lysed in a lysing buffer of PBS containing 1% Triton X-100 and 1% deoxycholate. F protein was purified from the crude cell lysate on an affinity column of Sephadex coupled to a murine monoclonal anti-F antibody, B4 (a kind gift from Hiroyki Tsutsumi) (Tsutsumi et al. 1987). The column was washed extensively with lysing buffer and

purified F protein was eluted in 0.1 M glycine pH 2.5, containing 0.1% deoxycholate. The eluate was neutralized immediately with 1 M Tris, pH 8.5 and dialyzed against PBS. After the detergent was removed on a Extracti-D gel column (Pierce, Rockford, IL, Cat. No. 20346), F protein concentration was determined by EIA and the solution was sterilized by gamma irradiation.

Lymphoid cell preparation:

Spleen was obtained following clinically indicated splenectomy of an idiopathic trombopenic purpura (ITP) patient. A single cell suspension was prepared by sieving through a metal mesh, and washed in IMDM media supplemented with 2% fetal calf serum. Red blood cells were eliminated by treatment with ammonium chloride lysing buffer for 90 seconds at 37°C. The white blood cell enriched suspension was then washed twice with serum containing media, resuspended in ice cold freezing media (95% FCS with 5% DMSO) at 10^8 cells/ml and frozen in liquid nitrogen until use.

In vitro immunization (IVI):

Cultures were set-up in IMDM supplemented with 2 mM glutamine, 2 mM sodium pyruvate, non-essential amino acids, 25 μg/ml IL-2 and 10% fetal calf serum. An antibiotics cocktail was added including 2.5 μg/ml amphotericin, 100 μg/ml ampicillin, 100 μg/ml kanamycin, 5 μg/ml chlortetracycline, 50 μg/ml neomycin and 50 μg/ml gentamicin. The cells were cultured in 6-well clusters at $3x10^6$ cells/ml with 40 ng/ml F protein. After three days, the cells were collected, washed and resuspended in HBSS at $8x10^8$ cells/ml for SCID reconstitution.

Reconstitution of SCID mice:

Five to eight week old female CB17/SCID mice were reconstituted by intraperitoneal injection of 200 μl of HBSS containing $4x10^7$ human spleen cells subjected to IVI; the mice were boosted one week later ip with 5 μg F protein in CFA and tail bled after another 15 days. Their serum was tested for human IgG concentration and anti-F protein antibody titer.

Recovery of human cells from hu/SCID mice:

Two hu-SPL-SCID mice with high anti-F human antibody titers developed large abdominal tumors. Tumors were recovered by excision from sacrificed mice under sterile conditions, single cell suspensions were prepared, the cells were washed with IMDM containing 2% fetal calf serum and cultured at 10^6/cells ml in T-25 flasks in IMDM with 10% FCS.

Testing for human IgG and anti-F protein antibodies:

The testing for human IgG and anti-F antibodies was performed in ELISA. For that purpose, plates were coated overnight with GAH-Ig (0.05 μg/well) or F protein (0.05 μg/well) respectively in 0.1 M bicarbonate buffer, pH 9.5 and blocked with PBS containing 1% fetal calf serum. Serial dilutions of mouse sera, culture supernatants or purified antibodies were reacted to the plate. Bound human IgG were revealed by the subsequent addition of GAH IgG- HRP and OPD substrate (Sigma,.. , ..). Selected high titer human serum was used as a positive control in both assays and purified polyclonal human IgG, or (γ, κ) myeloma protein were used as a standard in the estimation of the concentration of human IgG and monoclonal antibodies respectively.

Isotyping of human antibodies:

Isotyping was performed in ELISA on F protein coated plates as described above. Bound human IgG were revealed by the subsequent addition of HRP conjugated mouse monoclonal antibodies specific for human γ1, γ2, γ3, γ4, μ, κ and λ chains. Positive controls were run with myeloma proteins of the (γ1, κ), (γ2, κ), (γ3, λ), (γ4, λ) or (λ, λ) isotype and free κ and λ chains.

Protein A purification:

Antibodies were purified from culture supernatants on a protein A- Sepharose 4B column. Briefly, supernatants were collected, filtered through 0.2 mm filters and supplemented with 0.02% sodium azide. Columns (gel volume approximately 0.5 ml) were equilibrated in PBS with 0.02% sodium azide, then loaded with supernatant at

low speed. After extensive washing, bound human monoclonal IgG were eluted in 0.1 M sodium citrate buffer, pH 3.5, dialyzed against PBS-azide using Centricon 10 filters (Amicon, ,) and sterilized by gamma irradiation until further use. Columns were regenerated with citric acid pH 2.5 and re-equilibrated with PBS with 0.02% sodium azide for subsequent use.

Isoelectric focusing:

Isoelectric focusing (IEF) of human antibodies was performed in polyacrylamide pre casted gels (Pharmacia, Uppsala, Sweden, Cat. No. 80-1124-80), pH 3- pH 10. Briefly, 20 μl of samples were loaded and run at 1500 volts for 90 minutes. Standards of pi 5.8 to 10.25 were used for pi reference (...). Gels were stained in Coomassie blue stain and destained in destaining buffer containing 25% methanol, 68% water and 8% acetic acid.

Western Blot:

Purified F protein, both native and denatured by boiling, was migrated in a 10% polyacrylamide gel. The gel was blotted on a nitrocellulose sheet at 30 volts for 2 hours and 60 volts overnight. After transfer, the nitrocellulose was blocked for 1 hour at room temperature with 1% BSA and 0.1% Tween-20 in PBS. Different strips were washed in PBS and the primary antibodies, hu-SPL-SCID anti-F protein sera, or hu-SPL-SCID anti-tetanus toxoid negative control, or mouse anti-F protein positive control, were added for 1 hour. All sera were diluted 1:500. After extensive wash with PBS, the secondary antibody, GAH IgG- HRP for the samples and the negative control, or GAM IgG for the positive control, was added for 1 hour. Blots were revealed with 4-chloro-1-naphtol.

Immunofluorescence:

RSV infected HEp-2 cells (4 x 10^4) were fixed on glass slides using ice cold acetone and were reacted with 20 μl of serum diluted 1:10 or purified MAb, 2 μg/ml, for 1 hour at 37°C. The slides were washed and the bound antibodies were revealed

with GAH IgG-FITC, for 30 minutes at 37°C and observed under a fluorescence microscope.

FACScan analysis:

RSV-infected HEp-2 cells (10^6 cells/sample) were washed with washing buffer (PBS with sodium azide 0.1%). The cell pellet was resuspended in 50 μl of incubation buffer (PBS with sodium azide 0.1% supplemented with BSA 0.1%) containing 2 μg/ml RF-1 or RF-2. After 15 minutes incubation on ice, the cells were washed and resuspended in incubation buffer containing GAH IgG-FITC for another 15 minutes on ice. After 3 washes, the cells were fixed in 1 ml PBS with 1% formaldehyde and analyzed in a Becton-Dickinson FACScan apparatus.

Affinity determination:

Two methods were used to determine the affinity of human MAbs to soluble F protein:

In plasmon resonance, using an IASYS machine, antibody was bound covalently to the wet side of a device from which the change in mass can be determined based on the change of refraction of light shone on the dry side of the device. Different concentrations of F-protein were added and subsequently eluted off with a steady flow of PBS. The change in mass as a result of F-protein release from the antibody was measured, and from the kinetics a K_{off} was determined. Ka was calculated by testing the off-rate from different levels of initial saturation.

Alternatively, affinity constant was determined by micro-calorimetry according to Wiseman et al and Robert et al., as follows: RF-2 and F protein were co-incubated at a known concentration in a thermo-chamber at 42°C and the enthalpy change due to the immune complex formation in the solution was measured. The reaction was repeated at 50°C. The binding association constant K was calculated as a function of temperature and enthalpy change according to Robert et al. in the following equation:

$$K=Kobs.e^{\Delta Hobs/R.(1/T-\ 1/Tobs)}.e^{\Delta CTobs/R.(1/T-1/TTobs)}.(T/Tobs)^{\Delta C/R}$$

where Kobs is the binding equilibrium constant and ΔH^{obs} is the enthalpy change observed experimentally, at a given absolute temperature, Tobs; R is the universal gas constant (1.987) and ΔC is the experimentally determined binding heat capacity change.

Complement-enhanced virus neutralization assay:

Two laboratory strains (Long, type A and 18537, type B) and ten wild type RS virus isolates, which were isolated from hospitalized infants, were used to assess the neutralizing capacity of anti-F protein human MAbs. Serial dilutions of human MAb were pre incubated with virus (50-100 pfu) in the presence of complement for 30 minutes at room temperature, in 100 μl IMDM/well of microtitration plate. HEp-2 cells (5 x 10^4/well) were added in 100 μl MEM and incubated for 3 days at 37°C, 5% CO_2. The plates were washed, fixed with acetone and air dried and RSV antigen was detected by ELISA using mouse MAbs. The neutralization end point was determined arbitrarily as the dilution which reduced antigen production by 50% compared to control wells with no antibody.

Virus fusion inhibition assay:

Fusion inhibition titers were determined by pre incubating 100 $TCID_{50}$ RSV Long (prototype A virus) or RS 6556 (Type B clinical isolate) with VERO cells (5 x 10^3/well) in microtitration plates, for 4 hours at 37°C, 5% CO2. Various concentrations of human monoclonal antibodies or controls were added to each well and quadruplicate cultures were incubated for 6 days at 37°C, 5% CO_2. Control cultures contained virus non infected cells (negative) or infected cells in the absence of antibody (positive). Virus growth was detected in ELISA using rabbit polyclonal anti-F protein antisera and HRP-labelled anti-rabbit IgG. The reaction was developed with TMBlue substrate (KPI, Gaithersburg, MD). Titers (ED50) were defined as the concentration of antibody inhibiting virus growth by 50% based on regression analysis of the MAb dose response.

EXAMPLE 1

HU-SPL-SCID titers:

Fifteen SCID mice received human spleen cells from a single donor with ITP condition. The cells were previously cultured for three days in the presence of IL-2 and different concentrations of soluble F protein. All animals were successfully reconstituted and, after boost with F protein, total human IgG concentrations varied from 12 μg/ml to 10 mg/ml in the serum and anti-F protein titers varied from 3×10^2 to 10^6 (Table I). No correlation was observed between *in vitro* F protein exposure and anti-F protein titer *in vivo*. It has been previously observed with the subject method, in the horse ferritin antigen system, that antigen exposure is necessary during *in vitro* cultivation of the spleen cells to subsequently ensure specific antibody titer *in vivo*. The discrepancy between these two systems may be attributed to the difference in the antigens involved: since humans are not naturally exposed to horse ferritin, the IVI step involves an antigen priming of the spleen cells and induces a primary response *in vitro*; on the other hand, virtually all humans are immune to RSV through natural infection in early life, which leads to a permanent memory to F protein, therefore stimulation with IL-2 alone *in vitro* followed by one boost *in vivo* is enough to induce secondary responses.

The antisera were polyclonal, as judged from isoelectric focusing patterns (data not shown). They were tested for reactivity to F protein in Western blot. Our results showed that polyclonal human Abs did recognize soluble native F protein both in its dimer form (140 KD) and its monomer form (70 KD); they also reacted strongly with denatured F protein, binding specifically to the 2 subunits of 48 KD and 23 KD (representative data in Figure 1). This suggests that at least a fraction of the humoral response to F protein is directed against linear, non conformational epitopes of the molecule. Immunofluorescence studies further demonstrated the specificity of the hu-SPL-SCID sera, since immune sera, but not naive SCID mouse sera, reacted strongly with RSV- infected HEp-2 cells (Figure 2). No reactivity was observed towards non-infected HEp-2 cells used as negative control. It was concluded therefore that soluble

F protein was an adequate antigen for the generation of antibodies specific to the membrane viral antigen expressed on naturally infected cells.

EXAMPLE 2

Identification of antibodies in tumor cell cultures:

All mice with high anti-F protein titers were sacrificed and human cells were harvested from peritoneal lavage and spleens. Two mice (hu-SPL-SCID # 6 and hu-SPL-SCID #15) spontaneously developed abdominal solid tumors that were recovered and teased into single cell suspension. The tumor cells secreted specific anti-F protein antibodies as determined in ELISA. These tumors and antibodies are referred to as RF-1 (RSV F-protein) and RF-2. RF-1 and RF-2 were generated in two different experiments separated by approximately two months and were isolated from individual hu-SPL-SCID mice, and are thus distinct antibodies; they have established themselves in culture for more than 18 months and 16 months respectively, dividing with an approximate doubling time of 36-48 hours. Specific antibody concentration is typically of 0.5 - 1 μg/ml in a culture seeded at 0.5 x 10^6 cells/ml and grown for three days.

For further characterization, both human MAbs were purified from culture supernatants by affinity chromatography, using Protein A Sepharose columns. Both RF-1 and RF-2 are $IgG_{(\lambda,k)}$, with half maximal binding to F-protein in ELISA at 0.6 and 1 ng/ml respectively (Figure 3). From the migration pattern in IEF, RF-1 and RF-2 isoelectric points were determined to be 8.8 and 8.9 respectively (Figure 4). RF-1 and RF-2 specifically recognized RSV infected HEp-2 cells in flow cytometry (Figure 5). The dissociation constant, Kd, for RF-1 was determined by plasmon resonance on an IASYS machine to be in the 10^{-10} M range. The Kd constant of RF-2 was determined by titration micro calorimetry, according to Wiseman et al (1989) and Robert et al. (1989) to be $2x10^{-9}$ M.

EXAMPLE 3

Tissue specificity of anti-F-protein:

Purified antibodies were screened for reactivity to a series of human cell lines available at ATCC by means of indirect immunofluorescence assays measured by flow cytometry (Table II): The results showed that the antibodies did not bind to cell lines representing respiratory tract lining (HEp-2, a laryngeal epidermoid carcinoma, Cat. No. CCL 23), liver (HepG2, a human hepatoma cell line, Cat. No. HB 8065), lymphoid tissue (SB, a human B lymphoblastoid cell line, Cat. No. CCL 120 and HSB, a T lymphoblastoid line, cat.no. CCL 120.1) and prostate (LNCaP.FGC, a human prostate adenocarcinoma line, Cat. No. CRL 1740).

EXAMPLE 4

In vitro functional activity:

To determine whether the antibodies had virus neutralizing effect *in vitro*, they were subjected to two types of functional assays: Infection neutralization assays were performed by pre-reacting the virus with purified MAb prior to its addition to the cells and therefore reflect the ability of the MAb to inhibit virus infectivity; fusion inhibition reflects the ability of the Ab to inhibit virus growth and expansion after virus entry in the cell. The outcome of both assays was measured as the amount of virus released in the culture after a given incubation time, as determined by viral antigen titration in EIA.

Both Abs were able to inhibit virus infection, of all twelve isolates tested, at concentrations ranging from 30 ng/ml to 1000 ng/ml and from 8 ng/ml to 165 ng/ml, for RF-1 and RF-2 respectively. RF-2 performed consistently better than RF-1, yielding to 50% virus inhibition (ED50) at concentrations 1.25 to 10 times lower than RF-1. Representative data are indicated in Table III.

As expected, higher concentrations of MAb were required to inhibit fusion and viral antigen expression in previously infected cells. In this assay, RF-1 was 5 to 10

times more potent than RF-2. Both MAb were more effective in the Type B prototype RS 6556 than in the Type A prototype RS Long (Table III).

Table I

mouse #	[Ag] in vitro	fresh cells	hu IgG (μg/ml)	anti-F titer
1	1 μg/ml	+	1,000	10^6
2	1 μg/ml	+	12.3	10^3
3	1 μg/ml	+	3,000	10^6
4	1 μg/ml	+	8,750	10^6
5	1 μg/ml	+	1,000	10^6
6	1 μg/ml	-	1,500	10^5
7	1 μg/ml	-	162	10^5
8	1 μg/ml	-	4,500	10^6
9	1 μg/ml	-	333	10^5
10	40 ng/ml	-	3,300	$5x10^5$
11	40 ng/ml	-	554	$3x10^2$
12	1 μg/ml	-	10,000	$5x10^5$
13	1 μg/ml	-	200	$5x10^4$
14	0 μg/ml	-	182	$5x10^4$
15	0 μg/ml	-	3,300	10^5

Table I: Splenocytes from a single donor were cultured in the presence of IL-2 for 3 days, with or without F protein. SCID mice were reconstituted with $4x10^7$ cells and boosted with 10 μg of F protein ip in CFA. In mice # 1, 2, 3, 4 and 5, fresh autologous cells ($20x10^6$) were injected with the boost. Human IgG concentration was determined by comparison to a standard curve of polyclonal IgG and anti-F protein titer was determined by end point dilution in EIA.

Table II

Cell line	Tissue Type	Tissue Labeling
HEp-2	Laryngeal epidermis	-
RSV infected- HEp-2	Laryngeal epidermis (RSV)	++++
SB	Lymphoid	-
HSB	Lymphoid	-
LNCaP	Prostate	-
HepG2	Liver	-

Table II: Reactivity of RF-2 with various cell lines. Various cell lines were subjected to indirect immunofluorescence labeling with RF-2, 200 ng/10^6 cells. A Fab goat anti-human IgG-FITC was used as second step. (-) indicates the presence of RF-2 did not result in change of channel for the average fluorescence; (+) indicated increase of average labeling by 0.5 log.

Table III

Antibody	Fusion Inhibition activity ED_{50} titer		Antibody	Infection Neutralization Activity ED_{50} titer	
	RS Long (Type A)	RS 6556 (Type B)		MR 144 (Type A)	18537 (Type B)
RF-1	660 ng/ml	40 ng/ml	RF-1	30 ng/ml	30 ng/ml
RF-2	3300 ng/ml	400 ng/ml	RF-2	8 ng/ml	12 ng/ml

Table III: ED_{50} is defined as concentration of antibody inhibiting virus growth by 50% based on regression analysis of the monoclonal antibody dose-response.

EXAMPLE 5 (COMPARATIVE)

Induction of IgG Recall Responses to F-protein *in vitro*:

More than 95% of the population over 2 years of age have been exposed to, and responded successfully to RSV Henderson et al. J. Med. (1979), 300, 530-534. Challenge of spleen cell *in vitro* with RSV F-protein should, therefore, result in recall responses, and, indeed, mainly IgG responses were induced *in vitro* with spleen cells (see Figure 5). The optimal antigen concentration, 40 ng/ml, was at least one order of magnitude lower than what was observed for antigens inducing primary responses, i.e. ferritin, Ilig/ml, Boerner et al, *J. Immunol.*, 1991, 147, 86-95; Brams et al, *Hum. Antibod. Hybridomas*, 1993, 4, 47-56. Therefore, it must be considered that *in vitro* priming with F-protein induces secondary like responses. Several attempts to induce significant in vitro responses to RSV F-protein failed with PBMCs and tonsil derived cells.

A limited effort to generate monoclonal antibodies from in vitro primed spleen cells resulted in several monoclonal IgG antibodies to RSV F-protein. Most of these,

however, cross-reacted to one of several control antigens in ELISA (results not shown).

EXAMPLE 6

Cloning of the genes coding for RF-2:

Neither the RF-1 nor the RF-2 clone produce significant amounts of antibody. Also, both of these cell lines grow best in media with 20% FCS, which is disadvantageous because it results in contamination of the purified antibody with bovine IgG. Therefore, in order to be able to produce and purify amounts of antibody necessary for doing meaningful animal model tests, which typically requires up to 1 gram of one selected antibody, it is advantageous to transfer the genes coding for RF-1 and RF-2 to a production vector and cell line. The present assignee, IDEC Pharmaceuticals, Inc., has developed a very efficient eukaryotic production system which results in the production of human monoclonal antibodies in CHO cells. This vector system is described in commonly assigned U.S. Serial No. 08/379,072, filed January 25, 1995, and in commonly assigned U.S. Serial No. 08/149,099, filed November 3, 1993, both of which are incorporated by reference herein. Routinely using this system antibody gene transfected CHO cells produce around 200 mg antibody per liter of serum free medium in spinner cultures and greater than 500 mg/liter in fermentors after amplification in methotrexate.

Cell culture cloned (see below) RF-2 cells, approximately $5x10^6$, were subjected to RNA extraction using a mRNA isolation kit, Fast Tract (InVitroGen, San Diego, California), and single stranded cDNA was prepared using an oligo-dT primer and reverse transcriptase. An aliquot of cDNA was used as the starting material for polymerase chain reaction (PCR) amplification of the variable region genes. PCR was performed using two sets of primers. (see Table IV).

Table IV*

Heavy chain primers with Mlu 1 site

V_H1 5' $(AG)_{10}$ACGCGTG(T/C)CCA(G/C)TCCCAGGT(G/C)CAGCTGGTG 3'

V_H2 5 $(AG)_{10}$ACGCGTGTC(T/C)TGTCCCAGGT(A/G)CAG(C/T)TG(C/A)AG 3'

V_H3 5 $(AG)_{10}$ACGCGTGTCCAGTGTGAGGTGCAGCTG 3'

V_H4 5 $(AG)_{10}$ACGCGTGTCCTGTCCCAGGTGCAG 3'

V_H5 5 $(AG)_{10}$ACGCGTGTCTGGCCGAAGTGCAGCTGGTG 3'

Heavy chain constant region primer anti-sense strand with Nhe 1 site

IgG1-4 $(AG)_{10}$GCCCTTGGTGCTAGCTGAGGAGACGG 3'

Kappa Chain primers with Dra III site

1. 5' $(AG)_{10}$CCAGGTGCACGATGTGACATCCAGATGACC 3'
2. 5' $(AG)_{10}$CCTGGATCACGATGTGATATTGTGATGAC 3'
3. 5' $(AG)_{10}$CCAGATACACGATGTGAAATTGTGTTGAC 3'
4. 5' $(AG)_{10}$TCTGGTGCACGATGTGACATCGTGATGAC 3'

Kappa constant region primer anti-sense strand with Bsi WI site

C_k 5 $(AG)_{10}$TGCAGCCACCGTACGTTTGATTTCCA(G/C)CTT 3'

* Legend for Table IV: Synthetic oligonucleotide primers used for the PCR amplification of human immunoglobulin heavy and light chain variable regions. Restriction sites for cloning are underlined in bold.

The first set of primers was designed for amplifying the heavy chain variable regions. It consists of one 3 primer that binds in the J region and five family-specific 5' primers that bind in the late leader and framework 1 region. A second set of primers was designed for amplifying the Kapp variable region. It consists of one 3' primer and four 5' primers that bind in the late leader and framework 1 regions. The PCR reactions were electrophoresed on agarose gels and correctly sized 350 base pair bands were excised. The DNA was electroeluted, cut with appropriate restriction enzymes and cloned into IDEC's NEOSPLA expression vector. (*See* Figure 6) The

NEOSPLA vector used for expression of human antibodies contains the following: CMV = cytomegalovirus promoter, BETA mouse beta globin major promoter, BGH = bovine growth hormone polyadenylation signal, SVO = SV40 origin of replication. Nl = Neomycin phosphoamsferase exon 1, N2 = Neomycin phosphotransferase exon 2. LIGHT = Human immunoglobulin kappa constant region. Heavy = Human immunoglobulin gamma 1 or gamma 4 PE constant region. L = leader. SV = SV40 polyadenylation region.

IDEC's NEOSPLA expression vectors were designed for large scale production of immunoglobulin genes (*See*, Reff et al, Blood, (1994), 83, 435-445, incorporated by reference in its entirety). Mouse /human chimerics, primate/human chimerics and human antibodies have been successfully expressed at high levels using these vectors. NEOSPLA contains a neomycin phosphotransferase gene for selection of CHO cells that have stably integrated the plasmid vector DNA. In addition, NEOSPLA contains a dihydrofolate reductase gene for amplification in methotrexate, a human constant light chain (either κ or λ) and a human constant heavy chain region (either $\gamma 1$ or $\gamma 4$(PE)). Gamma 4 (PE) is the human $\gamma 4$ constant region with 2 mutations, a glutamic acid in the CH2 region which was introduced to eliminate residual FcR binding, and a proline substitution in the hinge region, intended to enhance the stability of the heavy chain disulfide bond interaction, Algre et al, *J. Immunol.*, 148, 3461-3468, (1992); Angal et al, *Mol. Immunol.*, 30, 105-108 (1993), both of which are incorporated by reference herein. Unique restriction sites have been incorporated into the vector in order to facilitate insertion of the desired and light variable regions. Reff et al., *Blood*, (1994), 83, 435-445.

The light chain of RF-2 has been cloned into NEOSPLA in duplicate and sequenced following the method of Sanger et al. Sanger et al., Proc. Natl. Acad. Sci. (1977), 74, 5463-5467. The kappa chain is a member of the kappa 2 subgroup. Similarly, the human heavy chain variable region of RF-2 has been isolated and cloned in front of the human $\gamma 1$ constant domain.

The light chain coding genes of RF-1 and RF-2 were readily cloned, whereas cDNA for the genes encoding the heavy chains could not be generated using the common Tac reverse transcriptase. However, this problem was obviated by

substituting a high temperature, 70°C, reverse transcriptase. Thereby, intact PCR products could be generated with primers primarily derived from V_H2 family genes.

The amino acid sequence and the nucleic acid sequence for the RF-1 light and heavy variable domains may be found in Figures 7a and 7b, respectively. The amino acid sequence and the nucleic acid sequence for the light and heavy variable domains for RF-2 may be found in Figures 8a and 8B, respectively. Figures 9a-9c depict the nucleic acid and amino acid sequence of RF-1 as expressed in the subject NEOSPLA vector. Figures 9a and 9b depict the leader, variable light and heavy, and human constant domain sequences, i.e., the human kappa domain and the human gamma/constant domain. Figure 9c shows the amino acid and nucleic acid sequence of the human gamma/constant domain. Figure 10 depicts schematically an expression vector which provides for the expression of the sequences set forth in Figures 9a-9c and thereby recombinant RF-1 in CHO cells.

Figures 11a-11a similarly depict the amino acid and nucleic acid sequences of the leader sequence, RF-1 variable light, human kappa constant region, RF-2 variable heavy, and human gamma/constant domain. Figure 12 depicts schematically an expression vector which provides for the expression of recombinant RF-2 in CHO cells.

EXAMPLE 7

Development of a protocol for cloning of EBV transformed cells:

Antibody production from EBV transformed cells continuously decrease, and ultimately ceases. Kozbor et al., J. Immunol. (1981), 127, 1275-1280. To immortalize the antibody production, it is therefore essential to extract the immunoglobulin coding genes from the cells before this event and transfer those into an appropriate expression system. In order to isolate the genes coding for the antigen binding variable domains of antibodies produced by EBV transformed cells, it is essential to ensure that the cell material is monoclonal. EBV transformed cells are, however, very difficult to clone whether by limiting dilution or in semisolid agar. Isoelectric focusing gel electrophoresis of protein A purified preparations of our two

anti-F protein antibodies, RF-1 and RF-2, showed at least two populations of antibodies in the RF-2 preparation and the possibility of oligoclonality in the RF-1 preparation.

By using the mouse thyoma line EL-4 B5 Zhang et al, *J. Immunol.*, (1990), 144, 2955-2960, as feeder layer, cells were expanded from a single cell through limiting dilution. The human thyoma cell line EL-4 B5 expresses gp39 in a membrane receptor way that induces B cells to grow. 5×10^4 EL-4 B5 cells/well were plated out in a microliter plate, and cells from the cultures were plated out on the EL-4 B5 layer at various concentrations, from 0.38 cells/well and up. The number of wells with growth for each of the concentration plated were counted after an appropriate amount of time.

The supernatant was tested for presence of human IgG and for antigen-specific IgG. With this protocol we have isolated and cloned the cells that produce RF-1 (see Table V) and RF-2 (see Table VI), respectively, from the original oligoclonal preparations. The non-specific antibodies found in the cloning were only analyzed with respect to isotype, and were found to be the same as the specific antibodies, IgG1k. Based on the yield of F-protein specific clones from freezes made at various time points during the cultivation of RF-1, as well as the amount of IgG that was produced, it was estimated that the specific antibody made up approximately 1/20 of the total antibody amount shortly after the start of the culture and disappeared after approximately 8 months in culture. RF-2 made up a much higher part of the total IgG, no less than 10 % at any given time. Antibody from the oligoclonal preparations was used to generate the in vitro neutralization data, resulting in an overestimation of the ED50 titers. Our affinity studies with plasmon resonance, however, were not dependent on using pure antibodies. The affinity studies using titration micro calorimetry was done with cloned material.

Table V*

# cells/well	# wells	# anti-F wells (%)	# wells with growth (%)
30	48	48(100)	48(100)
10	48	48(100)	48(100)
3.3	96	27(28)	68(71)
1.1	192	17(9)	112(58)
0.38	384	18(5)	116(30)

*Legend for Table V: Cloning of RF-1 by limiting dilution. EL4-B5 cells were plated out at 5x1O4 cells/well in a flat bottomed 96 well plate. Approximately 24 hours later, RF-1 cells in exponential growth were plated out on the feeder layer at the described concentrations. After 2-3 weeks, the wells were scored for growth and for presence of anti-F activity.

Table VI*

# cells/well	# wells	# anti-F wells (%)	# wells with growth (%)
30	40	40(100)	15(37.5)
10	120	120(100)	22(18)
3.3	120	102(85)	9(7.5)
1.1	120	50(41.6)	1(0.83)
.33	180	30(16.7)	5(2.8)

*Legend for Table XIV: Cloning of RF-2 by limiting dilutio/n. Done as in Table VIII.

In order to confirm the clinical applicability of the two human monoclonal antibodies with *in vitro* virus neutralizing activity, these antibodies are further characterized with respect to their efficacy in clearing RSV infection in two different animal models. These preclinical performance evaluations are effected with material produced by CHO cells transfected with the cloned genes coding for the antibodies inserted into a proprietary expression vector (see Figure 6). Two antibody models, one with intact complement and Fc receptor binding domains, γ1, and one void of these domains, γ4 (PE mutant), Alegre et al., J. Immunol., (1992), 148, 3461-3468; Angal et al., Molecular Immunology, (1993), 30, 105-108, will be tested. The rationale for testing γ4 version is based on two considerations: (i) Anti-F-protein Fabs have shown significant virus neutralizing effect in vitro Barbas et al., Proc. Natl. Acad. Sci. (1992), 89, 10164-10168, as well as in vivo, Crowe et al, Proc. Natl. Acad. Sci. (1994), 91, 1386-1390, albeit when administered directly into the lung, (ii) potentially avoiding lung damage caused by effector function activation in sensitive tissue already stressed by virus infection could be advantageous. A set of nonspecific control antibodies, one γ1 and one γ4 (PE), will be generated from an in-house non-specific hybridoma IgG_1 antibody.

The first animal model is a mouse model, Taylor et al., J. Immunology (1984), 52, 137-142; Walsh, E.E., J. Infectious Diseases (1994), 170, 345-350. This model is used to determine the effective dose, defined as the smallest dose resulting in a 2 log reduction in virus load in the lung tissue after 1 weeks incubation. This model is also used to determine which of the antibody models to proceed with. The second animal model is a primate model using the African green monkey, Kakuk et al, J. Infectious Diseases (1993), 167, 553-561. RSV causes lung damage in the African green monkey, and this model's main purpose is for evaluating the damage preventing properties of the antibodies. The number of tests with this model will be limited to test one antibody in 5 different doses. The antibody, the dose and the infusion date relative to infection date will be determined based on the findings with the mouse model. Lung section is examined for virus load in plaque assay and by light microscopy for detection of lesions caused by RSV.

It will be observed if any changes in the amino acid sequence have taken place during the process of stimulating and expanding the cells that produce the two antibodies. This is done by testing with a set of PCR primers based on the CDR3 regions of the heavy chains of RF-1 and RF-2 whether the sequences of the genes coding for RF-I and RF-2 are present in the original frozen cell material from which the two cell lines were generated. The positive control is RF-1 and RF-2 spiked source cells. The analysis follows the principles established by Levy et al., 1989, Levy et al., J. Exp. Med. (1989), 169:2007 and Alegre et al., J. Immunol. (1992), 148, 3461-3468; Angal et al., Molecular Immunology (1993), 30, 105-108; Foote et al., Nature (1991), 352, 530-532; Rada et al., Proc. Natl. Acad. Sci. (1991), 88, 5508-5512; Kocks et al., Rev. Immunol. (1989), 7, 537-559; Wysocki et al., Proc. Natl. Acad. Sci. (1986), 83, 1847-1851; Kipps et al., J. Exp. Med. (1990), 171, 189-196; Ueki et al., Exp. Med. (1990), 171, 19-34.

EXAMPLE 8

Generate CHO cell lines that produce large amounts (> 100 mg/liter) of RF-1 and RF-2:

a. Transfect expression plasmids, isolate and expand G418 resistant CHO clones expressing the highest levels of RF-1 and RF-2.

Once the RF-1 and RIF-2 variable region genes are cloned into NEOSPLA, Chinese hamster ovary (CHO) cells (DG44), Urlaub et al, *J. Somat. Cell Mol. Genet.*, (1986), 16, 555, are transformed with the plasmid DNA. CHO cells are grown in SSFM H minus hypoxanthine and thymidine (GIBCO). 4 x 10^6 cells are electroporated with 25 μg plasmid DNA using a BTX 600 electroporation device (BTX, San Diego, CA) in 0.4 ml disposable cuvettes. Prior to electroporation, the plasmid DNA will be restricted with Pac I which separates the genes expressed in mammalian cells from the portion of the plasmid used for growth in bacteria. Conditions for electroporation are 230 volts, 400 micro faradays, 13 ohms. Each electroporation is plated into a 96 well dish (about 40,000 cells/well). Dishes are fed with media containing G418 (Geneticin, GIBCO) at 400 μg/ml three days following electroporation, and thereafter, periodically, until colonies arise. Supernatant from colonies is assayed in ELISA for the presence of human IgG and for anti-F-protein activity.

b. Amplify the expression of antibody in methotrexate.

The G418 resistant colonies producing the highest amount of immunoglobulin are then transferred to larger vessels and expanded. The expression of the highest secreting G418 clone is increased by gene amplification, by selection in 5 nM methotrexate (MIX) in 96 well dishes. The 5 nM colonies producing the highest amount of antibody.are then expanded and then expression amplified again by selection in 50 nM MTX in 96 well dishes. Following this protocol, we have previously been able to derive CHO cells that secrete greater then 200 mgs/liter in 7 days in spinner culture (greater than 0.5 gram/liter in fermentors in 6 days). Human antibody is then purified from supernatant using protein A affinity chromatography.

c. Produce and purify antibody.

100 mg of each antibody is generated. The selected antibody is produced in amounts determined from the mouse model studies. Spinner flasks with selected CHO

transfectomas in CHO-S SFM II serum free medium (GIBCO Cat. No. 91-0456DK) with 50 nM methotrexate are used to produce antibody in the required amounts. Supernatant are harvested and filtered through a set of filters to remove particular material, ending up with a 0.2 nm filter. The supernatant is run through a protein A column with a predetermined size based on the total amount of antibody. After washing, the antibody is eluted from the column with 0.1 M Glycine/HCl, pH 2.8, into a neutralization buffer, 1 M Tris./HCl, pH 7.4. The elution/neutralization buffer is exchanged extensively, $\geq$1000 times, with sterile PBS by ultrafiltration through an Amicon Centriprep or Centricon 30 (Cat. no. 4306 and 4209). The concentration of antibody is adjusted to 2 mg/ml and sterilized by filtration through a 0.2 nm filter. The antibody is purified and stored on ice in 2 ml cryotubes until use in animals.

EXAMPLE 9

Characterize RF-1 and RF-2 in respect to performance in RSV animal models:

The performance of RF-1 and RF-2 is determined using appropriate animal models. The evaluation is divided into two steps, first (a) a Balb/c model, Taylor et al., J. Immunology (1984), 52, 137-142; Crowe et al., Proc. Natl. Acad. Sci. (1994), 91, 1396-1390; Connors et al., J. Virology (1992), 66, 7444-7451, to determine the potency of the antibodies, as well as to determine what type of support (effector) functions are essential for the antibody to clear the virus load. From the data gained in the mouse model, one candidate is chosen for further studies in a primate model. The primate model is an African green monkey model, Kakuk et al., J. Infectious Diseases (1993), 167, 553-561. A primate model is especially suitable for confirming that the subject monoclonal antibodies can be used to prevent virus associated lung damage.

a. Test performance in mouse model.

The rodent-model we have chosen is the Balb/c mouse. This model is well characterized, Crowe et al., Proc. Natl. Acad. Sci. (1994), 91, 1386-1390; Connors et al., J. Virology (1992), 66, 7444-7451, for studies on passive therapy studies.

Balb/c mice are highly permissive to growth of RSV in both upper and lower airways at all ages, Taylor et al., J. Immunology (1984), 52, 137-142. Animals are housed in groups of 5, fed standard mouse chow and water ad libitum and cared for according to the Rochester General Hospital vivarium guidelines. These guidelines are in compliance with the New York State Health Department, the Federal Animal Welfare Act and DHHS regulations. All procedures, including injections, virus infection, orbital bleeding and sacrifice by cervical dislocation, are performed under penthrane anesthesia in a vented hood.

i. Determine effective dose of antibody and compare performance of γ1 and γ4 (PE version) of RF-I and RF-2.

Groups of 5 mice are infected by intranasal instillation of 106 Long (subgroup A) or 10^5 18537 (subgroup B) plaque forming units (PFU) of RSV in a 100 μL volume on day 0. On day four, at peak virus titer, animals will be injected intraperitoneally with each of the four F-protein specific monoclonal antibody preparations or control antibody. The doses tested are initially centered around a reference dose calculated to provide a serum neutralization titer of approximately 1:300 or greater from *in vitro* studies. This titer has been associated with protective levels against challenge with RSV in small animals. Dose response is evaluated by treatment with 25, 5, 1, 1/5 and 1/25 of the reference dose. Experiments with higher or lower doses are performed if warranted. Control mice are injected with an equivalent dose of the isotype matched monoclonal antibodies, as described above. Twenty-four hours later; day 5 is the peak of virus shedding, the mice are sacrificed. Serum is obtained by intracardiac puncture and the nasal turbinates and lungs are removed, weighed and homogenized in 1 and 2 ml of NMM, respectively. Homogenates are titered for virus on HEp-2 cells, and virus titers expressed as $TCID_{50}$/gm tissue. The mean titers between groups are compared to the control group by the student t-test. Serum is obtained at the time of infection and at sacrifice for human monoclonal antibody quantification by enzyme immunoassay and neutralization assay. It is anticipated that the greatest reductions in virus titer will be in lung virus growth since IgG isotypes are not actively secreted (in contrast to IgA) in the upper

respiratory tree. Should therapy on day 4 of infection prove ineffective at reducing lung virus, therapy on days 2 and/or 3 will be assessed.

The titer of each monoclonal antibody in stock solutions and in serum from injected animals is determined using an ELISA,as described supra. RSV fusion protein purified by affinity chromatography according to established methods (82) is used in the solid phase. A separate assay for the RSV G protein will also be devised for evaluation of mouse IgG responses to experimental RSV infection. Rabbit antibody specific for human IgG and mouse IgG (available from Virion Systems, Inc., Bethesda, MD) is used to detect human monoclonal antibody or mouse antibody in the ELISA.

The dose response effect of the monoclonal antibodies are determined for the antibodies as the lowest antibody titer which reduces virus titers more than 2 $\log_{10}$ or >99% reduction in virus titer. The degree of protection are correlated to the serum antibody levels achieved at the time of sacrifice. In addition, the potential synergistic effect of various combinations of human monoclonal antibodies is determined. The results of the initial *in vitro* studies outlined above will be used to guide the in vivo experiments. For instance, if RF-1 and RF-2 have distinct antigenic binding sites on the RSV F protein, combinations of the same isotype (γ1 or γ4) may provide for synergistic protection.

ii. Histological evaluation of lung tissue.

The effect of passive therapy on lung inflammation is evaluated by standard histopathological and immunohistochemical techniques. Both peribronchiolar infiltrates and alveolar infiltrates have been described in the mouse following either primary or secondary infections, Conners et al, *J. Virology*, (1992), 66, 7444-7451. Experimental animals are treated with monoclonal antibody, as described above. Uninfected untreated control mice serve as comparisons for evaluating histological effects. On days 5 and 8 after infection, the lungs are removed and inflated with formalin under constant filling pressure (30 cm H_20) for 30 minutes. After sectioning and staining with hematoxylin-eosin, the degree of inflammatory infiltrate (PMN and lymphocytic separately) in the peribronchiolar and alveolar areas is determined using

a standardized scoring system. Since it is anticipated that the γ1 and γ4 monoclonal antibodies may fix and activate complement differentially, the lung sections are stained for mouse C3 deposition in areas of inflammation using a commercially available rabbit anti-mouse C3 antibody (Viron Systems, Inc. Bethesda, MD) and peroxidase conjugated goat and-rabbit IgG.

In addition to evaluation of histological changes seen in fixed pulmonary tissues, pulmonary inflammation is assessed by evaluation of alveolar cytology. Groups of mice, treated as described above, are sacrificed and a bronchoalveolar lavage (BAL) performed by repeatedly infusing 3 ml PBS into the lower airway. Cell counts of the BAL will be performed, and the cell type identified by staining of cytocentrifuge preparations.

iii. Effect of antibody therapy on the natural immune response to infection.

In the cotton rat and owl monkey models, passive therapy of RSV infection with polyclonal IgG preparations diminishes the subsequent natural antibody response to the virus, although animals are fully protected upon re challenge, Hemming et al., J. Infectious Diseases (1985), 152, 1083-1086; Prince et al., Virus Research (1985), 3, 193-206. In contrast, Graham found that treated mice had both blunted antibody responses and were susceptible to virus re challenge, Graham et al., Ped. Research (1993), 34, 167-172. To assess this possibility using human monoclonal antibodies, mice are infected with the Long strain of RSV and treated with a protective dose of antibody on day 4, as outlined above. Controls will include infected untreated animals, and uninfected treated animals. Mice are bled for antibody determination every other week for 8 weeks and then every 4 weeks for an additional 8 weeks. Both human monoclonal antibody and mouse antibody to the RSV F and G proteins are determined by ELISA. In addition, the neutralization titer of the serum determined at each time point. The contributions to neutralization by the residual human monoclonal antibody and actively produced mouse antibody are inferred from the ELISA results and by the results of neutralizing activity of the uninfected antibody treated controls. When human monoclonal antibody is undetectable by ELISA,

animals are rechallenged with the same strain of RSV. After 4 days, the animals are sacrificed and the lungs and nasal tissues titered for virus and compared to control groups.

In order to assess the impact of monoclonal antibody therapy on cytotoxic T-cells (CTL) induction, similar experiments are carried, but six weeks after infection, mice are sacrificed and spleen cell cultures stimulated with live RSV for 5 days, Walsh, E.E., J. Infectious Diseases (1994), 170, 345-350. CTL activity is assessed by standard Chromium 51 release assay using persistently infected Balb/c fibroblast cell line (BCH4 cells) and compared to an uninfected Balb/c fibroblast line.

Based primarily on the effective dose studies of passive therapy of established RSV infections, it is then determined which antibody, RF-1 or RF-2, is the most efficacious for preventing or treating RSV infection. The choice between the $\gamma 1$ or $\gamma 4$ (PE) versions takes the lung histology studies into account, in particular whether recruitment of complement appear to be significantly enhanced with the Clq binding antibody. Massive activation of complement could potentially have adverse effects, although enhanced vascularization that follows might increase the virus-antibody confrontation.

c. Test performance in monkey model.

The decisive test for the selected antibody is in a primate model. We have chosen the African green monkey (Cercopithecus aethiops) because it is highly permissive for RSV, and infection leads to enhanced lung pathology and detectable lesions, Kakuk et al., J. Infectious Diseases (1993), 167, 553-561. African green monkeys are also readily available and not endangered. This monkey weighs between 5 and 10 kgs. The highest expected maximal dose of antibody is 20 mgs/kg. Three animals of each 10 kgs with 20 mgs/kg equals 600 mgs of antibody. Some wild African green monkeys are naturally immune to RSV, and a requirement for entering monkeys into our study is that they are serum negative to RSV.

Based on the baseline established in the mouse model, effective dose/kg and infection time prior to therapy, a limited series of tests are performed in order to establish effective dose for virus reduction, as well as to confirm whether this

correlates with prevention of lung pathology, in particular parenchymal inflammatory involvement. Only one virus strain, Long (subtype A) is tested. Initially 25, 5, 1, and 1/25 times the reference dose is tested. Two control groups, one that receive virus but no antibody, and another that receives virus and maximal dose of the isotype matched control antibody, are analyzed. Essentially, the experiments are effected as described above. Monkeys in groups of 3 are also infected by intranasal instillation with 10^6 PFU of virus. Six to seven days after infection with virus the monkeys are sacrificed and lung and pharynx samples are taken for viral assays as described above and for histology.

Histology are performed essentially, as described above. Briefly, the lungs are perfused with 10% neutral buffered formalin under constant filling pressure. The lungs will remain in formalin for at least one week. After sectioning and staining with hematoxylin-eosin, the slides are evaluated histopathologically according to Kakuk et al., J. Infectious Diseases (1993), 167, 553-561. Serum samples are also be taken in order to determine the titer of human are antibody to RSV in ELISA and in Infection Neutralization assays.

EXAMPLE 10

1. Confirm tissue specificity by in vitro test on human tissue sections.

The antibody is then further tested for potential cross reactivity to normal tissues by immunohistology studies on different frozen normal tissue sections from two different individuals. Briefly, Cryostat microtome cuts of frozen tissues are subjected to 3 tests: Fixation analysis, a Nitration analysis and a specificity/ distribution analysis Purified biotin labeled anti-RSV F-protein antibody in PBS with 1% BSA is added, and the slide is incubated for 30 min. in a humidified chamber at 200C. The slide is then washed in PBS with I% BSA. The slide is subsequently incubated with Avidin-HRP in PBS with 1% BSA for 30 min. HRP is allowed to react with 3,3 diaminobenzidine-tetrahydrochloride, which forms an insoluble precipitate stain mediated by oxidation with HRP. This will identify any potential cross reactions of the subject human monoclonal antibodies. This test will be performed by Impath Laboratories, N.Y., N.Y, and is approved by the FDA for

I.N.D. submissions for products destined for human therapy. This histology approach uses pre-existing tissue and is less costly than the alternative, targeting studies of RSV infected monkeys with radiolabeled antibody.

CLAIMS:

1. A human monoclonal antibody which specifically binds the RSV fusion protein and which possesses an affinity for the RSV F-protein of $\leq 2 \times 10^{9}$ molar.

2. The human monoclonal antibody of claim 1 which neutralizes RSV *in vitro*.

3. A human monoclonal antibody which specifically binds to the RSV fusion protein which is selected from the group consisting of RF-1, RF-2 and recombinant human monoclonal antibodies which contain the variable heavy and light domains of either RF-1 or RF-2.

4. The human monoclonal antibody of claim 3 wherein said antibody is RF-1.

5. The human monoclonal antibody of claim 3 wherein said antibody is RF-2.

6. The human antibody of Claim 3, wherein said antibody is a recombinant antibody which contains either the human gamma 1, human gamma 4, or human gamma 4 PE constant region.

7. Eukaryotic cells which have been transfected with DNA sequences which encode for the heavy and light variable domains of either RF-1 or RF-2.

8. The cells of claim 7 wherein said eukaryotic cells are CHO cells.

9. The eukaryotic cells of claim 7 wherein said DNA sequences are selected from the DNA sequences set forth in any one of Figures 7a, 7b, 8a, 8b, 9a, 9b, 10a or 10b.

10. An Epstein-Barr immortalized B cell line which secretes a human monoclonal antibody which possesses an affinity for the RSV fusion protein of $\leq 2 \times 10^{-9}$ molar.

11. The cell line of claim 10 wherein said antibody neutralizes RSV *in vitro*.

12. The cell line of claim 10 wherein said cell line is selected from the group consisting of RF-1 and RF-2.

13. A method for producing human antibodies specific to the RSV fusion (F) protein which comprises:

(i)priming human splenocytes *in vitro* in the presence of IL-2;

(ii)transferring said primed human splenocytes into a SCID mouse;

(iii)boosting said SCID mouse with RSV F-protein; and

(iv)isolating human B cells from said SCID mouse which secrete human monoclonal antibodies specific for the RSV F-protein.

14. The method of claim 13 wherein said isolated human B cells are immortalized.

15. The method of claim 14 wherein immortalization is effected using Epstein-Barr Virus (EBV).

16. The method of claim 15 wherein said EBV immortalized cells are cloned using the mouse thyoma cell line EL-4 B5 as a feeder layer.

17. The method of claim 13 wherein the priming step is effected in the presence of IL-4 or IL-6.

18. A DNA sequence which encodes for the variable heavy and/or variable light domain of RF-1 or RF-2.

19. An expression vector which provides for the expression of a DNA sequence according to claim 18.

20. The DNA sequence of claim 18 which is selected from the group consisting of the DNA sequences set forth in Figures 7a, 7b, 8a, 8b, 9a, 9b, 10a and 10b.

21. A method for preventing or treating RSV infection in susceptible or RSV infected persons which comprises administering a prophylactically or therapeutically effective amount of one or more human monoclonal antibodies which possess an affinity to the RSV F-protein of $\leq 2 \times 10^{-9}$ molar and which also neutralize RSV *in vitro*.

22. The method of claim 21 wherein said antibodies are selected from the group consisting of RF-1, RF-2 and recombinant human monoclonal antibodies which contain the variable heavy and light domains of RF-1 or RF-2.

23. The method of claim 21 wherein said antibodies are administered by injection or by aerosol.

24. The method of claim 21 wherein said antibodies are administered in combination with an adjuvant.

25. The method of claim 24 wherein said adjuvant is Complete Freund's Adjuvant (CFA), Alum or a combination thereof.

26. A pharmaceutical composition suitable for preventing or treating RSV infection in susceptible or RSV infected persons which comprises a

prophylactically or therapeutically effective amount of human monoclonal antibodies which neutralize RSV *in vitro* and which possess an affinity for the RSV F-protein of $\leq 2 \times 10^{-9}$ molar and a pharmaceutically acceptable carrier.

27. The pharmaceutical composition of claim 26 wherein said human monoclonal antibodies are selected from the group consisting of RF-1, RF-2 and recombinant human monoclonal antibodies which contain the variable heavy and light domains of either RF-1 or RF-2.

28. A method of detecting the presence of RSV in an analyte which comprises incubating, said analyte with a human monoclonal antibody which possesses an affinity for the RSV F-protein of $\leq 2 \times 10^{-9}$ molar under conditions which provide for the formation of RSV F-protein antibody immune complexes; and

detecting the presence of said RSV F-protein antibody immune complexes to determine whether RSV is present in the analyte.

29. The method of claim 28 wherein said antibody is RF-1 or RF-2.

30. The method of claim 29 wherein said antibody is directly or indirectly attached to a reporter molecule.

31. The method of claim 30 wherein said reporter molecule is a detectable enzyme or radionuclide.

32. The method of claim 28 wherein the analyte comprises fluid obtained from respiratory tissue.

33. A test kit for assaying the presence of RSV in an analyte which comprises:

(i)a human monoclonal antibody having an affinity for the RSV F-protein of $\leq 2 \times 10^{-9}$ molar; and

(ii)a reporter molecule which is directly or indirectly attached to said human monoclonal antibody.

34. The test kit of claim 33 wherein said human monoclonal antibody is RF-1 or RF-2.